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CORRIGENDA.

Vol. 60, p. 257, col. 1, line 18: *For* "solenium" *read* "selenium."
p. 345, col. 1, line 44: *For* "strong" *read* "stiff."
p. 378, col. 1, at top: *Add* "1821 Faraday. First electric motor."
p. 378, col. 1, lines 6 and 7: *Delete* "and electric motor."
p. 378, col. 1, line 18: *For* "(H.M.S. 'Agamemnon')" *read* ", Charles (later Sir Charles) Tilston Bright, Engineer-in-chief (H.M.S. 'Agamemnon' and U.S.N.S. 'Niagara')."
p. 378, col. 1, line 40: *For* "Venice" *read* "Vienna."
p. 378, col. 2, line 30: *For* "1866" *read* "1886."
p. 407, col. 1, line 20: *For* "Desauty" *read* "de Sauty."
p. 417, col. 2, line 51: *For* "Elliott" *read* "Elliot."
p. 528, col. 2, line 38: *For* "Williams Premium" *read* "Willans Premium."

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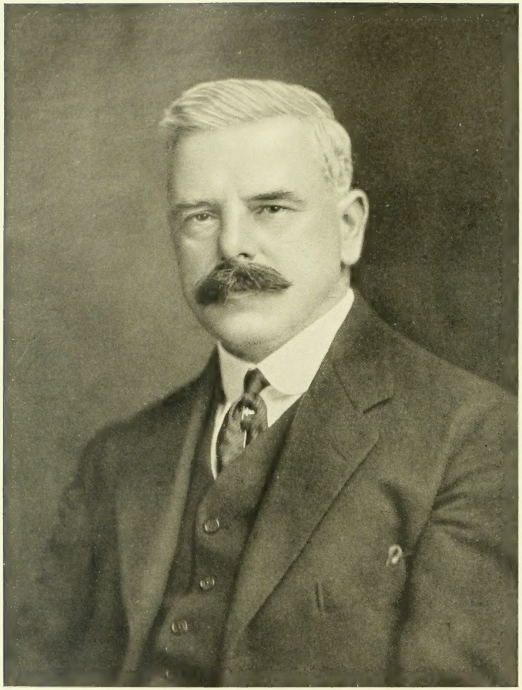

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THE JOURNAL OF

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VOL. 60.

INAUGURAL ADDRESS

By J. S. HIGHFIELD, President.

(*Address delivered 3rd November*, 1921.)

To be President of this Institution is to fill a position which, on the one hand, is a source of pride and, on the other, one of humility. I feel to the full both sensations. I have served fifteen years on the governing body of the Institution, including three years on the Committee of the Manchester Local Section, now the North-Western Centre, and have during that time enjoyed working with many earnest men among whom I am happy to count many friends, and I am very proud and very pleased to act for one year as the chosen leader of this Institution, whose dignity and prestige has to its members become a loving care. Again, I feel humble as I think of the opportunity of service offered, and of how far behind opportunity must lag individual effort.

Your elected leader primarily should serve as the eye-piece of an optical instrument, whose function is to produce an image. If we think of the members of this Institution as centres of radioactivity pouring forth rays of various colours, thermal and other qualities, these are collected by the object glass of Committee and Council and should be brought to a clear image in the person of your President. It is, in short, the business of your President to give point and definition to at least some of the common desires and interests of the members. The President of no body of men is better assisted to this end. Under the Council come our Territorial Centres and Sub-Centres, each in a measure autonomous, each depending on, and at the same time strengthening by direct representation, the central Council. Again, there are the Students' Sections, mainly managing their own affairs, learning the subtle secrets of organization and responsibility, and forming the recruiting grounds for our membership. We also have as part of the Institution the Wireless Section, and allied to us the Society of Radiographers, the latter an independent body but connected by the closest ties in interest, organization, and a common desire to pool information about all scientific and industrial work in which electricity plays a leading part. The value of this connection cannot be over-estimated; just as the so-called heavy engineering is continually dependent on the lighter branches, from which, through Faraday, it originated, so the lighter branches gather strength from the other which often can steady and simplify their designs. There are also the important Associations, the Electrical Development Association and the Electrical Research Association, in the welfare of which this Institution takes parental pride.

These various Centres and Associations, jointly with the Council, form a constitution of proved worth. It is designed, on the one hand, to preserve that continuity of growth based on tradition without which no structure, be it material or spiritual, can hope to attain strength and influence, and, on the other, to bring to bear new energy and new ideas so that yearly its youth may be renewed. The granting of a Royal Charter, together with the very greatest possible honour conferred on us by the King becoming our Patron, marks, I am sure we all feel, a great step forward. It is the highest public recognition of the work and importance of our Institution. It is also a change which throws on us all an added responsibility to maintain and strengthen our position, to enlarge the usefulness of the Institution not only to its members but to the public whom they serve. We are now a chartered Institution of Electrical Engineers under Royal Patronage; we must see that our efficiency is more than maintained and that the qualifying conditions for membership are raised as knowledge advances.

With a view to helping forward the Institution on well-trodden lines preserving continuity whilst aiding progress, I have studied carefully the addresses of the last three Presidents and those of Dr. Ferranti and Hopkinson in days gone by. I have chosen these five addresses for the reason that, from the first three, I am able to collect together recent tendencies, both social and technical, expressed in pregnant words by our last three most distinguished Presidents; Dr. Ferranti's illuminating address because he pressed forward the progress of electricity supply, on which depends in large measure the prosperity of the whole industry, and Hopkinson's because he was my teacher

and master. These addresses are full of interest; that of Mr. Atkinson is still fresh in our memory—it consists of a wonderful review of electrical work during the last fifty years, with a vivid guide for our direction in the future.

There is one outstanding feature of the last three addresses, and that is, that not one of the authors confines himself to technical matters, but all give considerable attention to questions both of education and of what are usually referred to as labour troubles. In the other addresses there is no such reference. The reason for this difference is obvious. The circumstances of these latter days have forced on the attention of all the fact that the body politic is not working smoothly, and surely it is instinctive in an engineer, when he sees defective working of any sort, to seek a reason; it is the first necessary step to the solving of any problem. Mr. Atkinson says: "Of what avail is it to continue to perfect the machinery of material civilization if, in the end, that civilization is wrecked because of the dissatisfaction of the people for whose satisfaction the perfecting is assumed to proceed?"

I agree, but the solution is no simple one. Mr. Atkinson says that discontent exists mainly because the people do not like their work. Again I agree, but what is the remedy?

Many, perhaps most, of us in one sense hate work, but without work we cannot live, and to live it is necessary to do many very dirty and unpleasant jobs. In our own work, boilers and condensers and flues must be cleaned; these are hard, dirty jobs. Then there is much work of a very monotonous kind, such as that of the shift engineer, monotonous, but varied by comfortable periods of wholesome excitement. A consulting engineer is generally supposed to enjoy a variety of interesting work, but fountains of speech in court and committee room, with hours of overtime at night to enable the flow to continue, is, to put it mildly, often a dull and exhausting performance. Many managing engineers could, I have no doubt, tell you of weary hours spent in arbitration in wages disputes, and in wrestling with Government regulations, meant to assist but generally hampering their industry.

Nevertheless, in all these and many worse occupations, I have seen men as cheery and gay as I have seen others gloomy and morose when engaged on what I thought to be the most interesting work. It may be said that a man will do any job if he is well paid for it. That may be, but the pay will not make him enjoy it, and that is the point. One of the first steps necessary to the enjoyment of any work is, I think, a personal knowledge of the possession of skill, the feeling that in some way, however small, we know that we can do the job in hand better than other people; the greater the knowledge of this skill the greater the pleasure. It is a subtle feeling, impossible of exact definition, and I think not requiring exact definition. It has its source probably in a feeling of rivalry, and this sense in its best form is greatly promoted by the national love of playing games, and in sport of every description. There is a splendid sense of pleasure in team work. I have helped reef a wet mainsail on a dirty night; followed behind an expert with a scythe through acres of grass; and acted as striker to a tool-smith. These jobs require as hard physical work as any, and call for considerable skill and the last ounce of effort, and for these reasons alone give pleasure, but the great source of pleasure is that you are doing a job in combination with other men more skilful than yourself, and that, nevertheless, you can just manage to keep up with them.

These are all manual jobs, and I suppose at least 80 per cent of the working population must be engaged in manual work, and from the point of view of works production it is clear that the efficiency is highest when the directing and designing staff is as small as possible in proportion to the number of direct producers.

Since the majority of workers must work with their hands, can it be said that our methods of general education are correct? So far as I have observed, and my views I know are shared by most of the men with whom I discuss this subject, the most proficient hand skill, and the most useful knowledge of some of the difficult industries such as farming, shipping, and engineering, are acquired and can only be acquired in boyhood. We know that the founders of our industry, Watt, Stephenson, Arkwright, Maudsley, Nasmyth, and Faraday, enjoyed the minimum of book education in early years. They spent those years working with their hands, nevertheless struggling to acquire book knowledge, and succeeding. We have in latter days reversed the process and made it easy to acquire book knowledge; nay more, we have made it imperative that every boy and girl should suffer the generally unpopular operation of having book knowledge forced into them, and we have neglected manual training. I know that many schools are moving in the opposite direction and are teaching art and hand skill at an early age, but I believe the process should be carried further; but this cannot be done unless the teachers themselves possess the necessary skill.

Every skilled trade is in its nature an art, just as music, painting and sculpture are arts, and all arts must be practised at an early age. Education, besides assisting in the perfecting of art, must be directed mainly to the formation of character, and continuity of education should be insisted on, so that no student leaves school or college with any other idea except that he leaves with a mental equipment designed for the acquisition of further knowledge. The best of education never can be proved by written examination. Personally, I value the opinion of a wise teacher about a boy far more than a mere record of the examinations he has passed. In life, knowledge and skill form the spear point; determination, wisdom and character are the shaft which gives the driving power.

This matter is all controversial; it can be discussed from all angles, and no finality is possible, but the controversy and discussion are not fruitless, and my object in enlarging on a subject raised by former Presidents, is to try to rouse a keener interest in this most important subject among our members. I offer no solution, but I hope to see more men outside scholastic circles giving their aid to find one. I want, as we all do, to see a greater England, a greater Empire, an Empire where every man may have a fair chance not only to benefit himself, but to benefit others,

and I hold that to this end the sound and sensible education of youth is of the first importance.

I use the term education to include all up-bringing, the formation of character, the means of health both of body and of mind, the Christian virtues, the love of work, the need of service, and the sacrifice, called duty, that alone should win us rights. These qualities can be won to the full only when there is ordered society, where there is that thing which the framers of the Electricity Act call a margin, and which ordinary men call a profit. Life mainly consists in a hard pull upstream, but, fortunately, there are softly washed shallows and quiet pools where for a time the struggle ceases. It is in the sunlit shallows and quiet pools that the fish breed, just as in life in the quiet pools of profit, strength, vigour and new ideas are born that enable the next push forward to be made. Through the War and since, we have all suffered from a spate which washed out the quiet pools and flooded the banks and reduced our river to a cataract. The spate has been followed by a horrid drought with which an engineer finds it still more difficult to deal.

I say an engineer, for I hold that no work falls to the lot of man more noble than that of the engineer. In a large measure he links up the work of the army of original thinkers. Clearly Engineering is the bridegroom to the fair bride Science, and the material progress of the last hundred years is largely due to their happy union. Without this material progress, the means to enable forty-five million people to live on these islands with increasing comfort, if they could have lived at all, would not have been attained.

This progress has been rudely interrupted, and it is certain that no rapid remedy is possible; only steady skilled application can produce any result. A slight scholarship acquired from books tends to make a man free of speech, ready to transmit to all, in a flood of words, solutions for making a new world. Years of book-study tend to complete silence. Our own education should be of real service. We know that hard constant work is required to resolve the simplest problem in engineering and science, we know that only sustained effort will produce any lasting result, and that time is requisite. We know that many have not that experience and still believe, about engineering and other matters, in the Fairy Wand by which results are achieved without effort and without time. Education is a matter in which engineers have had perforce to take an interest. After the steam engine was developed by Watt and Boulton to be a machine of great service, progress was rapid, and Maudsley, Nasmyth, Whitworth and other pioneers had of necessity to train their own men to repair and construct steam engines. Whitworth in his scholarships, and Robert Hammond in Faraday House, have as fine memorials as man can desire.

I am glad to note the important work recently done by electrical firms to better the training of their apprentices and technical assistants, and I think that every engineer in a managing position should do everything he can to assist in the education of his own men and of their sons. Scientific methods should be used. Scientific methods consist mainly in taking precautions against fooling yourself or being fooled, by applying, where possible, steady observation, and deducing by skilled thought true results from the observed phenomena. The effort made by every father in training his son is to give him the benefit of his own direct experience. Education should be directed to the same end, so that one generation may avoid the mistakes of those preceding it. This is the most difficult of all things to teach; it is so much more popular to teach the son or nation that never was there such a son or such a race. This is, of all methods, the most foolish and fatal to son and nation, and it is unfortunately one which is used by many of our so-called leaders. It is one which all experience shows to be nonsense, and which the application of scientific method to the study of past experience alone can prove to be false. Classical education aims at this study, and a more important one is not to be met with in the art of teaching. It will be a great day for our educational systems when the advocates of classical education see eye to eye with the modern side, so that the scientific method may be applied in the widest sense, and on the foundations of past experience be erected a sure knowledge.

I repeat that education should be directed to enabling every boy to acquire skill in a trade, and although the theoretical side of education acquired from books and bookish men is useful, the practical hand-skill, to be acquired only from hand-skilled men, is vital, and the sooner more attention is directed to this side of education the better. One of the nation's most valuable assets is a great body of men skilled in their trades, and taking delight and finding pride in their skill. It is an asset of greater value than easily-won raw material. There is a common trade pursued by what are called "unskilled" workers. It is a general term applied to a very large army of men, and it is a stupid term. There are very few jobs where no skill is required, and still fewer where skill is not useful. There are no unskilled trades, but unfortunately many unskilled workers. The skill of the artisan usually passes without notice, because few persons have the training and fewer take the trouble to apply scientific observation to the ordinary daily tasks performed by others, but a very little trouble will enable skill to be recognized in the doing of many so-called unskilled jobs.

There should be due reward for skill and industry. The Trade Unions have done much good for their members, but they have done at least equal harm, not only to their own members, but to the whole nation, by forcing the principle of standard wages and by reducing output. How can any proper man take pleasure in his work under such conditions, and since his life must be passed in work, how can he be happy unless he enjoys it? I hold it right, in a well-conducted State, that everyone should have the opportunity to earn a living, provided he will work, though it must be recognized that this happy state of affairs is one most difficult of attainment; it is a problem that has engaged and still engages the attention of statesmen, and it is not solved. It is only by fortunate environment, steady industry, and thrift among the general population, and good government, beginning in each home, continued by clever management in field

and factory, and extended by efficient and honest local and national government, that this state of affairs is possible. To complete my happy State, it is also necessary that each man should be willing to help the next, and to rejoice in his good fortune. To attain such success, the spirit of honourable rivalry should have full play, and this cannot be, unless each man is free to work as skilfully and as hard as he desires, and to attain a due reward for his labour.

Many of our members have a wide experience in directing men, and they know the value of the proper skilled man who loves his work. They know the heart-breaking task of directing ignorant and idle labour, and they also know—those who served in the War above all—what a real good fellow is the average man, always gifted with a kind and often with a lion heart. Our members, in this and other ways, have knowledge and often opportunity to take their part in helping their fellows to better education. The Institution work in this direction has been and is considerable. I hope to see the scope made wider. Let it be remembered that the best results can be attained only when profit enables those quiet pools to be created.

I have used the term "profit," and I believe the common misuse of the term is responsible for more than half our industrial difficulties. It is part of the creed of the engineer that terms must be defined, and at least half our fruitless arguments and most of our differences arise from the non-observance of this primary rule. Therefore, let me define profit. To the individual it is not what he spends on rent, rates and maintenance of himself and his family; it is not the sum he saves for old age or a rainy day, but it is what he can use to serve his desires whether in the form of sport or art, a present to his wife or children, or any other addition to the amenities of life, including the delight of charity. The amounts that may be so spent out of annual income are profit. But there is another method of expending profit, another sum which I include under the term, and from the industrial point of view a more important one, and that is the sum that each of us can devote to new ventures, including investment in the common stock of companies. All progress in science and engineering depends on the ability of the individual to venture his profit or part of his profit in this way, in applying part of his savings to new ventures.

It is, or should be, clear that national wealth (that is, the wealth of the nation as a whole) is created by individuals and belongs to individuals, and the most important and the most difficult problem a nation has to face is that of determining the share the individual must provide for common ends, and the means of giving him such continuing control in his property as will ensure its proper use. What has been done, apart from services necessary for the security of the State, to enable the individual's savings to be used for common ends? First, there are the laws relating to companies, that is, a body of men who elect to pool their savings to carry out business on a grand scale rather than on separate and smaller lines. We, as electrical engineers, are particularly interested in public companies. It is due to the thrift and enterprise of the shareholders in these companies that there is any electrical business. There is no more democratic institution than a limited company. The individual ventures his savings to any amount he thinks fit, and has votes in proportion to his holding; he elects his board of directors, one or more of whom retire annually; he may elect any shareholder, provided he holds a reasonable but very moderate number of shares, and he elects his own auditors to act as a check on the directors' statement of account. Note that the check is not a check on policy—the shareholders must attend to that—but simply on the directors' statement of account. Usually, when all goes well and reasonable dividends are paid, the shareholder is satisfied to re-elect his directors, but when dividends fall off he quite rightly wants to know the reason why, and he is given by law every opportunity to do so. Consequently, there is continually at work a compelling influence tending to maintain efficiency of direction and management, and the rough measure is profit. It is only a rough measure, but it is one perfectly easily understood by all, and in any democratic institution a ready, if approximate, means of measurement of efficiency is more important than a very accurate means difficult of understanding.

We hear so much of profit-sharing schemes that it is important to realize exactly what is sharable profit. The profit is part of the gross revenue; that is the total receipts in any year. Out of the gross revenue must be paid the cost of raw materials necessary to carry on the business, and the wages and salaries of the men who use the raw materials to produce the finished product. These must receive at least a sufficient wage to enable them to live efficiently. Then come rates and taxes, the contribution of the business for services rendered by men employed by municipalities and the Government; this is mainly a further payment for wages and salaries, and at the present rate it is a service which business cannot afford. Finally there are the rent of premises, the cost of management and other items included in the general term "overhead charges," which must be paid. When the sum of these costs is deducted from the gross receipts, there should remain a balance, a net revenue, out of which must be paid the interest on borrowed money. All these payments must be made, otherwise the venture is a failure.

Of any remaining sum, the first call is for depreciation and reserve, that is a sum to make good not only the actual wasting of plant and other assets, but their failure to earn profit. This question is complicated and I do not wish to deal with it exhaustively. It is of the first importance and cannot be too closely studied by those engaged in the conduct of business. It includes the actual wearing out of plant, and the value of plant superseded by better plant; it also includes the very important matter of holding sufficient cash or credit to enable the growth of the business to be met.

I find it convenient to bulk these items together and to consider that every year a certain proportion of capital employed in the business ceases to earn its proper proportion of net revenue, and that an equal sum must be retained out of the net revenue to replace the loss.

This amount having been set aside, the dividend on preference shares must be paid, and, from any sum remaining, a dividend on the ordinary shares. Before any profit can be said to accrue, this dividend should be at a reasonable rate, having regard to the prospect of it continuing to be paid. Any sum left over after this dividend is paid may be called profit, and in my view it should be employed equally to benefit those who direct and work the business, the shareholders who bear the risk, the consumer by way of a reduction in price, and lastly some share for the business itself. It is this last portion which can be applied safely for research in new methods and in new ventures, from which arise the means of reducing prices.

Any business is indeed fortunate when its staff, its men, its customers and its shareholders each and all desire to acquire shares; such complete unity of purpose makes for both enterprise and stability. There is no more sure proof of the soundness of any business than when the employees invest their savings in it; they will do this only if the business is prosperous and they believe the prosperity will continue. Unfortunately, little attention, so far as I have observed, has been given to the importance of profit by electrical engineers. Great attention has been given for years to the reduction of cost, and with excellent results. Almost equal attention has been given to low average prices, but very little to profit, which is really the important matter. When profit is earned, prices can be reduced and, if this be wisely done, the result will be increased profits. The effect is cumulative and leads to expansion of business, with continually decreased prices, because money is easy to raise and, consequently, is cheaply raised.

Reverse the process and allow profits to vanish either by careless attention to the costs or by unnecessary reduction of prices. What happens? Reductions, where possible, are made in the staff, wages are reduced and men turned off. Investors in shares vanish, money can be borrowed only at high rates and must be used as sparingly as possible, and orders for new plant are delayed. In short, every possible present economy must be exercised, and at the same time prices where possible advanced, until by this painful but necessary process profit is restored. Profit, in short, is the grease which lubricates the wheels of progress; it is the certain sign, the proof-plane of successful business; it is the starboard light which gives the right of way to enterprise. Without profit, if an industry does not die it can live only in a state of suspended animation.

In outlining the salient facts of revenue and costs leading up to my definition of profit, I have had in mind public utility services and similar stable businesses. The conduct of these is relatively easy, compared with, for instance, farming, shipping, mining, and manufacturing. In these, one year's results give no true measure of profit; a longer period is necessary; it is also less easy to avoid loss, as more conditions for success are beyond control and judgment; almost acquired instinct is needed to estimate their value.

Losses must be faced in any business, and anyone claiming a share of the profit in good times must equally be prepared to share the losses in bad times. The profits, in fact, belong to those who are able and willing to shoulder the losses.

I have spoken mainly of the great business of electricity supply, because I am familiar with its technical and financial aspects, and because it is the foundation on which the whole electrical industry is supported. If electricity supply flourishes, manufacturers of plant, cables, lamps, motors and all necessary apparatus flourish. Electricity helps every manufacture and trade, and active trade causes a greater use and demand for all means of communication, telegraphs, telephones, railways and shipping.

Therefore, I desire to speak further about the business of electricity supply. The Report of the Electrical Trades Committee of 18th April, 1917, contains these words:—

"Through the efforts of Faraday, Wheatstone, Kelvin, Swan, Hopkinson, and many others, Great Britain was, and should have continued, first in electrical enterprise. The nation's pre-eminence in all branches of engineering provided a foundation upon which the new and closely allied electrical industry might have been naturally and quickly built up. In order, however, to bring electrical energy into practical use it was necessary to employ cables . . . the installation of which involved interference with streets. . . . Manufacturers of electrical plant have been held back while Parliament and local authorities debated how the distribution and use of electricity might be prevented from infringing conventional conceptions of public privileges and vested interests. . . . While America, Germany, and other countries were eagerly seizing the benefits of electricity, our authorities were busied with the erection of obstacles to its development. Thus for years this country stood still, leaving the field open for foreign manufacturers to gain, both in their own and other markets, a hold which they have never lost. Abroad there were strong encouragements, in Great Britain irksome restrictions, and the evil effects on the British electrical industry justly entitle it now to special remedial measures, which can be secured only by legislation. Such legislation should be passed without delay."

This is, unfortunately, all too true. The difficulties were caused by the opposition on the part of many earnest thinkers and more ardent partisans to public utility business being undertaken by the enterprise of private citizens with their own money. There may have been reasons for the objection, but the fact remains that private enterprise has originated every march forward in engineering and other business, and continues, under Acts of Parliament designed for the protection of the public, to conduct all the great carrying and supplying trades. Railways, shipping, manufacture, farming and the great trades of the merchant and banker, all are in private hands. These great companies and organizations should be a source of pride, as they are a benefit to the nation as a whole.

I refer to these past troubles not with any desire to take sides or to renew the stupid controversy of private and municipal trading. The important matter is to trade, whoever does it, and it is simply wasting time to pursue a barren argument.

I have said that the really important matter at the present time is to get on with the work, and since a great part of electricity supply is carried on, and carried on very well, by municipal Corporations and Councils, I want also to say a word about their constitution and methods. The theory of municipal trading is that the citizens should, through their properly elected representatives, provide their own urgent wants. Electricity has been regarded, and rightly so, as a necessity, for although the number of inhabitants directly paying for it may be a moderate proportion only of the population, indirectly, through its use for railways, tramways, the driving of factories, and street lighting, the bulk of the population have great interest in securing a cheap and abundant supply. It is claimed for municipal trading that the supply can be more cheaply provided than by companies, for two main reasons, one is that the payment of directors' fees is avoided, the other that money can be more cheaply raised on the credit of the general rate-paying capacity of the whole community than by a company on its own credit, the credit created by the belief that it can pay and continue to pay dividends.

Doubtless, both contentions are in a measure true: there are no directors' fees, and the rate of interest paid on borrowed money is usually less on municipal loans than on a company's debentures. This, however, is only part of the story; the municipality can borrow money only if it undertakes to repay it by a sinking fund which is an annual sum coming from the pockets of the consumer. It must also provide a reserve, the greater part of which should be used to provide new plant. The sinking fund and reserve are equally direct charges against the revenue, but whereas one continually weakens the cash position, the other strengthens it.

The annual contribution to the sinking fund is money which is paid away to the man who lent the money; the annual contribution to reserve is hard cash with which plant may be bought.

A municipality should create a reserve, and many wisely do so, but the advantage of the low rate of interest on loans is largely wiped out by the annual sums that must be set aside out of revenue for sinking fund and reserve. In fact, the municipal undertakings have charged upwards of $1\frac{1}{2}$ per cent of the capital employed in excess of the charge made by companies.

In the public services, both company and municipal methods have been employed on a large scale; both have in the main produced excellent results, and both will continue. The company method is, I think, the better because it throws a more severe and direct burden on the shoulders of the management and, consequently, tends to greater efficiency. A company also can undertake new methods involving risk, and there are many in sight for electricity supply.

I have recited these elementary facts about the finance of enterprise, because failure to realize their importance so often brings the work of the engineer to naught. It is no use devising new machines for saving working costs if the expense of putting them into use results in capital charges that exceed the saving in working expenses. It is no use effecting savings if the results are all given to the public; part should go to the industry, part to those who work, and part to those who venture their savings on its behalf. The fault of mis-spending the profits is a capital one. In company working, it generally takes the form of paying too high dividends at the expense of reserve, and so the business is starved. In municipal working, it is common to appropriate too large a proportion of the profit to the relief of the rates; it is much better to buy new plant and avoid raising fresh loans, especially at the present time. The Electricity Bill of 1919 originally provided that all savings should enure to the consumers, clear evidence that its framers neither paid attention to business principles nor showed any knowledge of human nature.

I hope to see more engineers take a scientific interest in the finance of the works they control and design, so as to help in their better management. It should be realized that savings are invested in enterprise only with the hope of profit, and that those who shoulder the responsibility for financing industry carry a very heavy burden. On this subject I quote the words of Lord Kelvin on retiring from this Chair on the 9th January, 1890. They show the wonderful range of his sympathy and understanding.

"The Institution of Electrical Engineers has for its province practical applications of electricity and allied branches of science. But science, whether of electric instruments or of nautical operations, or of the heavy engineering work of stress and strength of materials and machines for working with cables in depths of from two to three nautical miles, cannot go on without the sinews of war; and I feel that those who have supplied the sinews of war, and have stood by from the beginning of the submarine cable enterprise up to the present time, ought not to be forgotten by an Institution of Electrical Engineers. I had myself the honour of being a shareholder in the first Atlantic cable of 1858. I had the honour and pleasure of having as a co-director Mr. Pender, now Sir John Pender. We did all we could in 1857 and 1858. We laid a cable a fifth of the way across in 1857, then a cable the whole way across in 1858.

"A great many people do not know that in 1858 there was a cable completed across the Atlantic to Heart's Content, in Newfoundland, and that messages were transmitted through it for three weeks—some exceedingly important public messages that saved many thousands of pounds, as countermanding the moving of two regiments ordered over from Canada to help to quell the Indian Mutiny. The return of those two regiments from Canada was countermanded because the Mutiny was already quelled while they were still under orders to leave for India. I remember the words being spelled out—'To the Military Secretary, Montreal.—The 60th Regiment is not to leave; the 61st Regiment is not to leave'; or words to that effect. I know it was to the Military Secretary; I am sure the 60th Regiment was one of the two. The return of the regiments was effectively countermanded through this cable, the very existence of which seems to be regarded as a myth. Amongst the directors of that enterprise Mr. Pender remained from 1858 to 1865.

"I myself, I am sorry to say, was able to do nothing

for cable work from the time of the failure in 1858–59, except in consulting and advising as to designs, until my assistance in the nautical and instrumental work was called for in 1865–66. Without the persistent, strenuous, and self-sacrificing determination of such men as Sir John Pender and some of his colleagues the enterprise would have died—absolutely died. Cyrus Field, from the other side of the Atlantic, helped to keep it alive; he gave help and impulse where they were required; worked with those who did not require revivification; and he, with his English colleagues, revived the undertaking in 1865. Then came the sad and dreadful discouragement in 1865, when half the cable was laid, and the 'Great Eastern' returned, having just succeeded in proving that Sir Samuel Canning's and Sir James Anderson's and my own belief was correct—that it was possible to lift it. In 1865 they got the broken end three times from a depth of 2 000 up to 500 fathoms from the surface, and each time it fell away by reason of breakage of the grapnel-rope.

"The third time of grappling—I think it was the third time—the cable came up with the rope foul of the grapnel. The grapnel was let down a fourth time, and brought up the cable once more within 500 yards, when it again broke, and the 'Great Eastern' returned.

"We were all dispirited in a sense, but not discouraged. Then, when we got back to England, with a fresh prospectus drawn up on board the 'Great Eastern' for an enterprise to make and lay a cable to Trinity Bay in 1865, come back to mid-ocean, lift the broken end of the 1865 cable, and complete that cable also to Trinity Bay, the crisis came, and the crisis was a financial one. Sir John Pender gave a guarantee of a quarter of a million sterling for the funds required to complete the enterprise of two cables across the Atlantic. Without that guarantee many and many a year would have passed before we should have had the Atlantic crossed by cables, and before ocean telegraphy would have had the great advance it has had. I repeat that a Society of Electrical Engineers has a double duty—a duty to science, to get all the good it can out of science; a duty to satisfy those who pay for the work that the work is good, a duty to encourage them to bring forward new work and to show that new enterprise has a chance to be successful."

Bearing this double duty in mind, there is much technical work in front of engineers that will tend to the expansion of business.

A reduction in the cost of transmitting electricity is of first importance. We are far from the end of invention in this matter; new methods are required. There is more water power available in this country, and especially in Wales and Scotland, than has been realized, and in this connection the work of the Water Power Resources Committee—consisting largely of our own members—is to be commended. But the fullest use of these resources depends on cheap transmission. The cable makers have done much to help, and have succeeded, despite increased costs, in improving the design of cable so as to transmit electricity at little more than the cost before the War. The greater facilities for overhead lines given by the Electricity Act are useful, and should give opportunities for providing electricity in many districts, especially rural districts, impossible by underground cables. Attention should be directed to the means of connecting the lines to the consumers' apparatus; switchgear and other subsidiary plant should be simplified even at the expense of security, in order to reduce cost. In the past we have been very careful to provide a secure supply, but in view of the reduced wealth of the nation, I think we have gone too far in this direction. Many manufacturers are content to depend for the running of their mills and works on a single gas or steam engine, and suffer occasional stoppages, which they regard as events which cannot be avoided except at prohibitive cost. We can easily give greater security than this, without unnecessary safety devices or an undue amount of spare plant, and there is no sense in trying to provide more, since there is not the money to pay for it. In short, our attention should be directed, and in fact is being directed, to amending design so as to reduce cost.

On the management side of the business, there is the important problem of arriving at a satisfactory tariff.

The maximum price in the Electric Lighting Orders was, with certain exceptions, 8d. per unit, and this price was subject to revision in most Company Orders every five years, but not in the Municipal Orders. The price was a sufficient one in the days of the carbon lamp; in fact, there was usually a considerable margin between the price charged and the maximum price. The introduction of the wire lamp, and its general use about 1910, resulted in the cost of lighting by electricity being reduced by more than one-half, and for a time the suppliers' profits fell off considerably, and it was only through the growth of the power and heating loads that suppliers were able to provide electricity for lighting without adding to the price per unit.

Further improvements in lamps have resulted in the cost of electric lighting being again reduced by about one-half, so that, had the price been doubled, the cost of electric lighting would still have been at least one-half that in 1908, and the revenue from the lighting of small premises is now so small as often not to pay the cost of service charges. In short, the lighting consumer has not paid his fair share of the increased cost. The result is that in many districts the cost of electricity for power and heating has, of necessity, been retained at too high a figure.

It is now generally realized that the tariff should be arranged so that two meters are not required. It is most desirable that the consumers should obtain the benefits of electricity for all purposes without being put to the cost of double wiring. This necessitates a system of charging which will enable electricity for all purposes to be supplied through one meter on what is known as the "Contract System" or "Two-part Tariff." The Electrical Development Association have done excellent work in pressing that the "Two-part Tariff" should be made a legal tariff. Before the War, in thousands of cases, the "Contract System" was used, the alternative being a flat rate of, say, 8d. per unit. Owing to the great increase in cost, it has not been possible to

maintain the "Contract Tariff" with a maximum price of 8d. per unit and the system has fallen into disuse, but since practically all items of cost are at the present time twice what they were in 1908, the logical thing would be to double the maximum price. This would enable the price for lighting to be raised to a reasonable figure and would avoid the necessity of overcharging for power and heating. It would also enable the "Contract" or "Two-part Tariff" to be put into use at once, with a resulting benefit to the industry and to the consumer.

Apart from this technical work, progress in electricity supply rests first on a general determination to cease talking and to get to work. We must necessarily depend for guidance on the Electricity Commissioners, and I am sure the general view, and certainly my own, is that they provide for the supply industry a skilled tribunal in which increasing confidence is being placed. They have a very difficult task to perform, and all the help we can give them should, and will, be given.

The difficulty of their task was enormously increased by the Act that gave them a constitution. It gave them too little freedom from political control. It equipped them with duties both executive and judicial. This combination of duties necessarily increases their difficulties, and, if my humble opinion be of any value, they should concentrate on the judicial and advisory side of their work.

Among the duties of the Commissioners is the fixing of maximum prices, and I have unfortunately found a tendency to exercise too much control, a tendency to fix the actual selling price and not the maximum price. Before the War there was a wide margin between the price charged and the maximum price, and the margin is necessary to meet contingencies. There has been delay in dealing with applications. I think that we had all hoped that our Commissioners would be free from red-tape methods, but I am sorry to observe signs of that baffling material.

The question is important to us all, not only to the electricity supply industry. In my own direct knowledge, several hundred thousand pounds have been lost to the industry through delay, most of which would have been spent with electrical manufacturing firms for extension of plant and cables to supply waiting consumers with the electricity they desired.

I make these remarks in no carping spirit. I am sure the Commissioners, men whom many of us know and greatly respect, desire to form an ideal Government office; and I think it is doing them a disservice to allow faults to pass unnoticed, and I know they will not resent fair criticism which is one of the sources of efficiency. The efficiency of a Commission possessing far-reaching powers is vital to the electricity supply industry, and to the whole manufacturing industry of which it is the foundation.

Any public service must of necessity be subject to some degree of control. The important matter is that this control be directed with understanding and with sympathy. There is, I am sure, a general belief that these qualities will be shown by the men chosen as Electricity Commissioners. Their efficient work will depend on close co-operation and firm trust between them and the industry; given this, the Commissioners should be of great service in removing, in a fair way, all those obstacles which have, for so long, restricted full development.

What are the main obstacles to rapid progress? The first, I think, is a feeling of uncertainty and insecurity, unfortunately created by the Electricity Supply Bill as first presented. This threatened the existence of every company undertaking and contained admittedly unfair proposals for purchase of both municipal and company works by new State-aided boards. These boards were to carry out in all industrial districts the work for which the Power Companies were established with Parliamentary sanction. This feeling of uncertainty still exists in spite of the fact that in the Act this feature was removed.

This feeling can be dissipated only by a clear proof that, in any schemes, the existing rights, both of companies and of municipalities, will be respected. The restoration of confidence, by a feeling of certainty that such is the policy of the Commissioners, is of the first importance.

Second in importance, I think, is that companies and municipalities should realize that they are both charged with the duty of providing the public with electricity, and should help each other to supply it in the least expensive way. I was delighted to welcome the Address of the President of the Incorporated Municipal Electrical Association. It is a courageous and just statement of the proper relations of companies and local authorities, and, if the advice be acted on, it should not be long before real progress is made in electricity supply.

The third obstacle to progress is the purchase clause in Provisional Orders. The twenty-one years' clause in the Act of 1882 absolutely stopped progress for six years. The present clause severely hampers the industry, and I should like to see it revoked unconditionally. I am aware that this is a radical suggestion, but I do not make it lightly. No single change would do more to promote enterprise and to supply the public at the least cost; any conditions must necessarily be paid for by the consumer. All the technical improvements in sight would not produce the beneficent results that would follow this change. It would enable much obsolete plant to be scrapped which now must be kept. It would give heart to the director who desires to raise more capital and to push forward his business, but who dare not and cannot raise money, when he may be forced to sell the undertaking in a few years. There would not be the very necessary tendency to keep prices as high as possible, in order to provide a sufficient reserve to purchase new plant to continue the business, and to provide for an unknown future. Again, the waste consequent upon a change of ownership of a great public business is enormous, and results in an increased price to the consumer.

The difficulty about the change is that the right of purchase is a Parliamentary bargain. The local authorities are entitled to enjoy it, and the difficulty can be overcome by their good offices alone, but since their desire is to benefit the general body of ratepayers,

and since cheap electricity is so desirable, I hope they may consider the suggestion in the most liberal spirit and try to find a solution of the difficulty.

I hope you will forgive me for dwelling on matters of money and trade. My excuse is the present very serious state of business generally, and the urgent necessity to rebuild our export trade. This depends on a healthy home trade. Home and export trades are mutually dependent, and since the prosperity of one trade usually helps others, I hope that all our members, while actively pushing their own businesses, will do what they can to help their friends. In this connection, the buying of goods from abroad is a matter that requires attention. I do not wish, in this Address, to raise all the complex issues involved in the political term "Tariff Reform." The reasons for buying foreign plant are often sufficiently good. At the same time, it should be recognized that the price paid to the foreigner is not necessarily the whole sum paid; some portion of the price may take the form of increased payments in taxes and rates to provide for unemployment at home.

I have spoken to-night of profit, and of what can be achieved in art and science, in education, and in general progress, when profit is earned. I am conscious that at the present moment profit is no longer earned by the great trading community of these islands, and that, in consequence, many are wanting work and many are in distress.

There is, in fact, no general board, no managing director, nor can there be one, for this vast trade, and when even the Government seek to fill the position they necessarily fail to produce any result but confusion.

As a trading community, we must reduce cost and increase output, and also, where possible, the reserve, and we must, as any trader has to do at times, reduce prices to re-open markets, even if an apparent loss result, and all concerned must shoulder their share of the loss.

Each trade, and each trading association, must attend to its own affairs and restore its own profit, to lead to the common end of restoring national prosperity. Masters should instruct their men and make clear the conditions for success. They are taking more trouble in this matter than has been usual in the past, and I have no doubt that the result will be an understanding and co-operation between masters and men better than have been known for years. They will go forward together, it may be in poverty, but at any rate with the certainty of improvement.

The problem is urgent. It must be tackled in detail. Success may be long deferred, and for a complete solution the limit is infinity. For our own trade, I have no doubt that it will do its share of the work, and since the traders in electricity are generally in a better position than many others, their responsibility to push on with the work is greater. In this, I am sure our members and this Institution will take a leading part, adding to their own usefulness and to our Institution's splendour.

NORTH-EASTERN CENTRE: CHAIRMAN'S ADDRESS

By Professor W. M. Thornton, O.B.E., D.Sc., Member.

IONICS, OR ELECTRICITY IN GASES AS A BRANCH OF ENGINEERING.

(*Address delivered at* Newcastle, *24th October*, 1921.)

Introduction.

The object of this Address, which will be a running commentary on the experimental illustrations, is to show the essential unity and simplicity of the phenomena of electricity in gases as applied to a wide and varied group of engineering problems. Gas ions are the working substance of a branch of engineering related to electrical engineering in the same manner as hydraulics is related to mechanical engineering. If the scope of this branch of applied science should ever warrant a distinctive title, I would suggest that of Ionic Engineering, or Ionics, to compare with Hydraulics, and if necessary it might include ionization in liquids.

Fifty years ago Maxwell predicted that research on electricity in gases would be the avenue by which the constitution of matter might be penetrated. This has been wonderfully justified, but we are far from the end. It is easy to utilize molecular energy, to make and unmake molecules; the whole science of chemistry and of organic life depends on the power to do this. There remains the stupendous step of unlocking atoms into their component electrons on an engineering scale, and the still greater feat of untwisting electrons into their mother ether.

This would be the end of physical analysis; beyond it there is the problem of how to make electrons. So far as inorganic matter is concerned, that would certainly be the end of synthesis, for if, as seems probable, positive and negative electrons differ only in the direction, right or left hand, of their twists, no new kinds could be manufactured, nor could man-made matter differ essentially from that we now know.

Our present knowledge, which extends by observation of spectra to the farthest visible star, is that there are only two kinds of electricity, the units of which are minute permanent right- and left-handed strains of the ether, and that all atoms are groups of these two kinds. A loose charged molecule is a possible ion or moving carrier of electricity. Since molecules of gases are separated more than those of liquids, the phenomena depending on ionization in gases are on the whole simpler than those in liquids. We begin then with the two kinds of gaseous ions, positive and negative, and study their production and behaviour in electric fields of every possible type.

Radiation.

Radiation from flame is by far the most important practical electrical property of gases. By it we receive the sun's heat. Energy is radiated in ether waves whenever an isolated charge or an atom, a system of both kinds of electric charges, is accelerated or retarded, as when it is thrown into vibration by high-velocity collision. Radiation from a vibrating atom is analogous to the sound from a bell when struck.

At least a fourth part of the energy of the coal burning in a boiler furnace which reaches the water is transmitted to the heating furnace by electrical radiation from the atoms in flame and incandescent coal. It is an important fact that radiation from any part passes through the rest of the flame without loss or interference, so that all reaches the iron walls and is there absorbed according to the law by which electrical radiation is absorbed by conductors.

Taking the total boiler power in the world as 50 millions of horse-power, at least 12 millions are transmitted to the furnace walls by short ether waves, making 300 or more billion (10^{12}) oscillations a second, from atoms in the furnace acting as electric radiators. The negative electron is light and easily moved compared with the positive electrons or protons which form the nuclei of atoms, and it is known from spectroscopy that radiation is set up by oscillation of the negative units only, either radially or by flexure of their planes of rotation. Compared with the sun's heat this is a small thing. The total power received in full sunlight on the illuminated half of the earth is 270 billion horse-power, all arising from vibration of atoms in the gases of the sun.

Electrical Ignition.

Next in engineering importance to radiation is electric ignition. The phenomena here are of great complexity, the nature of the combustible gas, its proportion to air, its pressure, the manner of formation of the spark, the constants of the electric circuit. All of these have been examined and certain facts emerge. Ignition proper is not primarily a thermal process; that is, it does not depend upon there being a certain quantity of heat in the spark. It has been shown to be, in the simple case of a jump spark, a purely electrical process. The gases of the explosive mixture are activated or ionized both positively and negatively by the field across the gap, and are then ready to enter into combination when a molecule of combustible gas collides with one or more of oxygen. The results show that of these the oxygen ion is first in importance, and since oxygen is electro-negative it is the negative charge that is most active in promoting ignition in gases; but the effect is transient. The gases must be freshly ionized at a

certain critical intensity for combination to follow collision. How to produce this ionized state in the most efficient manner is the problem of the magneto industry.

There are three ways in which electrical action on gases may cause ignition through direct intense ionization: by collision of electrons with molecules as in a jump spark, by ionic emission from arcs or their poles when a circuit is broken, and by thermionic emission from hot wires. Of these the first is the most effective in gases of high inflammability, such as petrol vapour or coal gas, the second in poor mixtures such as blast-furnace gas. The last is chiefly considered in its relation to danger of ignition of gases in coal mines.

Diesel Engine Ignition.

In the Diesel type of engine there is no direct electrical ignition, but a certain temperature by compression is necessary. Considering all chemical combination as electrical in origin there are here two possibilities, either that the velocities of high-temperature collision are those at which ionization by collision with electrons can occur, or that at the ignition temperature the energy of atomic collision and vibration is such that intense pulses of ether waves are sent out which ionize the adjacent gas molecules after the manner of X-rays but more intensely, or that there is some form of thermionic emission from the gas molecules themselves. The absence of influence of magnetic fields on the velocity of transmission of a gaseous explosion favours the second hypothesis. The products of combustion, the exhaust of an internal combustion engine, always carry a strong positive charge; that is, any negative ions made have been used up in the process of combustion.

Preventive Engineering.

The two great applied sciences which have brought the modern civic university into being are medicine and engineering. That prevention is better than cure is a commonplace of the one; it is no less true of the other. The prevention of short-circuits and the interruption of supply on the one hand, and of ignition in the case of coal mining, form, together with all arrangements for the prevention of shock, the greater part of this branch of the subject. Ironclad switchgear is an example of precautions taken to avoid flashing-over following ionization in gases. All air is excluded, and in the most modern forms of making contact there is no possibility of live metal coming permanently into contact with air.

Alternating currents are safer than direct currents for the reason that gaseous ions gather velocity in a continuous field, and are more active in promoting ionization; but in an alternating field they are swept to and fro over a short range and only acquire the energy requisite for ignition in much stronger fields.

Ignition by Hot Wires.

When a hot-wire lamp is broken in an explosive gaseous mixture ignition is possible but not certain. A blow that cracks the glass and admits gas may not fracture the filaments. It is safer when it does. As the temperature of a hot wire placed in an inflammable mixture is raised, nothing happens below about 200° C. At this temperature, far below red heat, a discharge of electrons from the wire begins, shot out of the metal by the energy of their internal bombardment; for negative electrons are always moving about freely in metals. When a voltage is applied to a wire they are driven by the field, are accelerated, and collide with molecules, raising the energy of vibratory movement of the latter so that the wire becomes hot. As the velocity of the electrons increases by their own acceleration in the field and by contact with vibrating molecules, a point is reached where they can escape from the metal, like steam from hot water. The gas around the wire is ionized by this high-velocity discharge, and slow chemical combination begins. The temperature of the surface then increases until the gas burns freely in contact with the wire at a white heat without flame. This is the phenomenon of surface combustion in which the greater part of the energy is in the form of radiation. In coal mines any exposed hot wire may be dangerous though there is no open sparking and though the wire may be in appearance cold. Under certain conditions positive ions are produced by hot wires.

Electric Arcs.

The crater on the positive pole of an arc is a target kept hot by being shot at by negatively charged particles of molecular dimensions discharged from the negative pole, and by a stream of electrons from it at a velocity of several thousand miles a second. There are in the arc positive ions discharged from the positive incandescent surface under the influence of the field. The gas between the carbons is polarized, and there is therefore an apparent back electromotive force located chiefly in the gas film at the crater of the positive pole. The theory of the arc is still incomplete and has, in any case, had little influence on the practical design of arcs. The oscillations which can be made to occur in an arc circuit promise to be more far-reaching and permanent, in radio-engineering for example, than the use of the arc as a source of light, except for searchlights.

Arcs in Vacuum Tubes.

Electrical discharge in gases at low pressures is of great engineering interest. For certain purposes the mercury-vapour lamp still holds its own. Its mechanism is as follows. At the working pressure of 1/80th of an atmosphere the space is filled with mercury vapour. An arc is struck between mercury drops forming a chain, and is drawn out to fill the tube, the vapour conducting the current by a series of collisions of positive ions with electrons moving in the opposite direction, the consequent vibrations of the mercury atoms causing the peculiar colour of the arc.

Arc Rectifiers.

When the voltage is alternating there is in the tube a volume or space charge lasting from the first half period. The movement of the ions though rapid is not so quick that their positions in the tube can be instantly reversed. The space has therefore a quasi polarity which persists though the voltage is rapidly

reversed. Current flows in one direction better than the other and there can be complete rectification. Rectifiers of this type are now built to transmit 1 000 kW or more by electrified molecules of mercury vapour.

Vacuum Tube Discharge.

The importance of electrical discharge in high vacua is in the development of the X-ray tube and of the triode valve. X-rays are extremely short ether waves set up by the collision of electrons discharged from the cathode of a vacuum tube. This electron stream, which always starts at right angles to the cathode, can be focused on to an anticathode, in modern tubes a block of tungsten. Its velocity may reach 6 000 miles a second, and its heating effect on impact is considerable. From the violent collision of the electrons with the anticathode, X-rays are generated set up by the vibrations of the atoms struck. The space in the tube is partly polarized and the tube acts as a valve.

The triode valve is a modification of the vacuum tube by the insertion of a grid between the electrodes, one of which is an incandescent filament, the other a cold metallic plate. The negative discharge from the filament passes through the grid on its way to the plate, but, by giving the grid a voltage opposing or aiding the flow, the discharge can be held up or accelerated. Thus, not only does the tube act as a valve but as an amplifier, the energy of the amplified wave being supplied by the battery between the filament and plate. By connecting an inductance across the tube, tapping it at one point to the grid, and using a condenser to store the energy of oscillations which occur when certain critical conditions of current and voltage are satisfied, the valve can be made to give continued oscillations at high frequencies, and can therefore be used instead of a machine as a generator of waves in radio-telegraphy. As much as 5 kW have been given out by a single valve and, by coupling these in parallel, large antennæ currents have been obtained. The future of radio-telegraphy lies with the ionic valve and the continuous wave it emits.

Ozone.

When electrical discharge takes place in air at atmospheric pressure, not as streaming sparks but as a corona glow, intense ionization by collision is produced. At low temperatures nitrogen compounds are very little formed and the effect is almost confined to activation of the oxygen which, under the intense electrification, appears to break up and recombine to form ozone. This gas has three oxygen atoms to the molecule and is stable. It is manufactured on an engineering scale for bleaching or preserving foods and oils. The special interest here is that in general it is the negative ionization which is effective, and that when electrical discharge just falls short of the spark stage it is the oxygen that is ionized first with a negative charge. When streaming sparks pass with more positive ions nitrogen compounds are formed. This point is of importance in the theory of ignition and in the protection of high-tension switchgear from the destructive action of ozone and nitric acid formed in sockets and on insulating surfaces.

Nitrogen from Air.

Air is a mixture of nitrogen and oxygen in the proportion of 4 to 1 by volume. There are six oxides of nitrogen, but their rate of formation in air is so slow that self-ignition cannot proceed, otherwise the surface of the world would vanish in one vast explosion. Under the action of streaming electric sparks they form gaseous compounds which, when washed, pass into solution and are utilized by chemical processes to form artificial manures or, in times of war, explosives. The latter depend for their violence on the instantaneous liberation of large volumes of nitrogen from the combination of the solid salts which form the explosive substance. The importance of the production of solid nitrogen compounds is recognized in Germany, where many thousands of tons are made per year. In Scandinavia the electric arc method has been worked to a high pitch of efficiency. Britain, in her usual manner, is the last country to place extensive manufacture of nitrates on a sound basis. A plentiful supply of nitrogen for manures with extensive mechanical cultivation of the ground, in fact more co-operation between engineering and agriculture, must come if we are to hold our own under all circumstances of peace and war.

The theory of the reactions in the electric arc or spark is not fully known. Both oxygen and nitrogen are ionized, and ionization by sparking of both gases before entering the furnace separately improves the yield.

In the case of switchgear the solution is to avoid all spaces of air in contact with high-tension conductors of small diameter, or with sharp edges, on which "corona" might form.

Smoke Deposition.

Just as rain, when electrified, coalesces and falls in the large drops characteristic of a thunder shower, so clouds of smoke can be treated to cause an aggregation and deposit. The essential is a strong electric field sufficient to produce clouds of ions, electrons or charged molecules, and to sweep them into contact with the smoke particles, charging them in turn and carrying them still colliding and gathering together to the separator. The reason why small charged particles collect to form a larger mass is that the total potential energy of a number of charges or surfaces of small diameter is greater than that of the same total charge spread over the surface of a sphere in which all are collected. Any system with potential energy when left to itself will move so that the energy is lowered, as a ball runs downhill. The success of such an apparatus depends on the excess of one kind of ion, and in this discharge it is probable that the negative ionic discharge plays the leading part. There is not much possibility of treating the atmospheric pollution of large towns by electrical means. A simpler solution is the use of coal from which the smoky constituents have been removed by low-temperature distillation.

Smoke deposition by electrification is, however, making rapid strides, and it promises to be one of the most useful applications of science in recovery processes.

Atmospheric Electricity.

The electricity of the atmosphere is by no means negligible in its bearing on engineering operations. The upper layers, ionized by radiation from the sun, form a conducting sheath enveloping the sunny side of the earth. This sheath has great influence on the propagation of electric waves and on the success of radio-telegraphy and telephony.

Electrical phenomena on or near the earth's surface are rarely beneficial in an engineering sense. Electric storms are the bane of telegraphists, and in certain parts of the earth—South Africa, for example—they are of sufficient violence to shut down large overhead power systems. When a strong wind blows through a mist both are electrified, the water drops positively, the air negatively, and when this occurs on a large scale several thousand feet above the earth's surface in conditions favouring the formation of large clouds, there is "thunder weather." In addition, evaporation is always accompanied by electrification of the liquid and vapour, so that in the tropics there is always a disturbed electrical state. When again a wind blowing over a dusty or sandy plain raises clouds of dust there is intense electrification. The potential of the dust, as a system of particles, is raised by their separation, there being enough electrification of the surface to start the process. The necessary energy is supplied by the kinetic energy of the wind.

Both kinds of ions are formed, which, when separated by the normal electric field from the earth's surface, collect on the clouds on the one side and on the earth, leading, when the pressure is piled high, to lightning discharge between them.

To counteract the interference with power supply there is no remedy but safety valves for excess pressure-surges and the avoidance, as far as possible, of running power lines through lands having a loose and dusty surface.

The subject of "atmospherics" in wireless is a great and open problem. They may arise, for instance, from immense and rapid movements of ionized air at very low pressure on the confines of the earth's atmosphere, or from corpuscular or other radiation from the sun passing or reaching the earth. Means are now being devised of working through them, but this ever-present disturbance of the ether is one of the most disturbing consequences of electricity in gases with which the resources of engineering are called upon to deal.

Conclusion.

The phenomena described fall into four groups, as follows :—

(1) *Ions produced by collision between electrons and molecules in intense electric fields.*

	Nature of Field
	High Voltage
(i) At atmospheric or higher pressures.	
(*a*) Ignition by jump sparks.	Linear, concentrated.
(*b*) Ozone by corona.	Radial, concentrated.
(*c*) Nitrogen by streaming sparks.	Irregular.
(*d*) Smoke deposition.	(*a*) and (*b*) combined.
(ii) At low pressures (1 cm mercury).	*Low Voltage*
The mercury vapour arc.	Linear.

(2) *Ions produced by thermionic discharge.*

(i) The triode valve.	Radial and linear.
(ii) Hot-wire ignition.	Radial.
(iii) Arc phenomena.	Linear, high gradient.

(3) *Electrical effects of collision.*

(i) Electrons with a solid body. X-rays, low gas pressure. Arc light, atmospheric pressure.	High linear electric field.
(ii) Between molecules. Radiation from incandescent gases, atmospheric pressure.	No external field.

(4) *Electrical effects of separation of charges.*

Atmospheric electricity. Evaporation. Dust.	Low.

Each of these groups has at least one head of engineering importance and, taken as a whole, they constitute a branch of applied electricity or electrical engineering which promises to equal in importance the engineering of fluids or hydraulics, and which gives even greater opportunities for the exercise of experimental research, mathematical reasoning, and judgment in the use of materials, which are the essentials of engineering science.

SOUTH MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By R. A. Chattock, Member.

(Abstract *of Address delivered at* Birmingham, *2nd November*, 1921.)

South-west Midlands Electricity District.

I think it will be perhaps instructive for me to discuss a subject of great public interest just now, viz. the scheme that is being put forward to deal with the South-West Midlands Electricity District which, as you are aware, has been delineated by the Electricity Commissioners under the Electricity (Supply) Act, 1919.

Under this Act the Electricity Commissioners set out to reorganize the supply of electricity throughout the country. They commenced by delineating certain districts in the country and asking interested parties to submit schemes for dealing with the supply in those districts, with a view to making available a cheap and abundant supply of electricity for all purposes.

The Act in question contemplates the formation of Joint Electricity Authorities for such districts, where deemed necessary. It is intended that these should control the whole of the generation of electricity in the district; take over the existing generating stations; provide further generating facilities, either by extending existing stations or by erecting new capital stations; and also provide main transmission lines for distributing electricity in bulk to the various distributing authorities in the district.

The Act does not, however, make the formation of Joint Electricity Authorities compulsory, and schemes embodying other forms of control are admissible.

The Commissioners have up to the present held Inquiries into schemes submitted for several districts. These schemes, some of which have been approved, have all contemplated the formation of Joint Electricity Authorities. The procedure under the Act requires these approved schemes to be developed and published and further Inquiries to be held upon them, with a view to considering any suggested alterations.

After final approval, the Commissioners will make Orders giving effect to them. These Orders have to be confirmed by the Minister of Transport and subsequently approved by both Houses of Parliament.

It will be seen, therefore, that some considerable time must elapse before a scheme can be put into operation. On this account no experience has yet been gained of the actual formation of a Joint Electricity Authority, or of its operation in practice. Sufficient evidence has, however, been forthcoming to show that the working of Joint Electricity Authorities is likely to be attended by considerable difficulties.

The representation of the great number of interests involved in a district is likely to make the controlling body rather unwieldy. Again, in most districts these interests include both municipalities and companies, and it is recognized that it will be very difficult to reconcile the combination of the interests of these two sections of the community on a single controlling Board. This is especially the case as regards finance.

In the South-West Midlands District there are two large existing undertakings which together are responsible for the generation of about 98 per cent of the total current. I refer to the Birmingham Corporation and to the Shropshire, Worcestershire and Staffordshire Electric Power Company. The difficulties I have outlined above were fully recognized by these two bodies, and led them to endeavour to evolve a scheme in which the difficulties could be satisfactorily obviated without impairing the efficiency of the scheme or interfering with the benefits to be obtained by a reorganization of the supply of electricity.

The two bodies felt that, in view of their great preponderance (from an electrical point of view) in the District, they were justified in suggesting that the control of generation in the whole of the District should be placed in their hands.

They have consequently submitted a joint scheme to apply to the whole of the South-West Midlands Electricity District, the proper control of which it is proposed to effect without the formation of a Joint Electricity Authority.

The general outline of the scheme is as follows:—

The District is to be divided into two sections, that section within the County of Warwickshire being under the control (as far as the generation of current is concerned) of the Birmingham Corporation, and the remaining section in Shropshire, Worcestershire and Staffordshire, under the control of the power company.

These supply authorities are to be responsible for the generation and bulk distribution of current to their respective sections, subject to the rights of one or two smaller existing generating authorities in the District to continue to run their generating stations.

The systems of the authorities promoting the scheme are identical as regards frequency, voltage, etc., and it is proposed to connect their capital stations together by means of a substantial electrical link, so that they may, if necessary, render assistance to each other, and so that the best and most economical use of the plant may be assured.

It is proposed to set up a small Advisory Committee composed of representatives of the two bodies, this Committee to advise upon such matters as:—

The operating time-tables of the undertakings, with the object of securing an ample supply of electricity in the District;

The best load factor obtainable;
The conservation of fuel;
The proper return upon capital moneys expended and to be expended;
The standardization of systems;
The regularizing of the supply to conform to the requirements of the District;
The expenditure of capital moneys on extensions from time to time; and
The directions or suggestions of the Electricity Commissioners.

The Advisory Committee will make recommendations on such matters to its constituent authorities, but it shall not be competent for the Committee to incur any capital expenditure or to borrow moneys for such purpose.

Generally, this Committee will form a connecting link between the Electricity Commissioners and the various authorities in the District.

Let us now consider the engineering proposals in the scheme.

As regards existing generating stations belonging to the two main authorities, it is proposed to retain as much of the plant in these as is proved to be sufficiently economical in operation, and gradually to scrap the uneconomical plant.

It is also proposed ultimately to build three capital stations; the first of these has already been commenced by the Birmingham Corporation at Nechells, and will have an ultimate capacity of 105 000 kW. Plant of a capacity of 45 000 kW is at present being installed in this station, and the balance will be put in as the demand in the District requires.

The next station to be equipped will be one of similar capacity, which is to be built at Stourport by the Power Company on the River Severn. This will be connected with the Nechells station by means of 33 000-volt underground trunk cables.

In order to meet further developments, a large site has been acquired to the east of Birmingham at Hams Hall, where a station having an ultimate capacity of 300 000 kW is contemplated. This, again, will be linked up with the other capital stations in the District. The facilities on this site are, however, such that an increased capacity can be accommodated if necessary.

It will be seen, therefore, that provision has been made for meeting a demand of 500 000 kW and upwards in the District. This should be ample for many years to come, and can easily be extended if necessary.

It is proposed to equip these stations with large-capacity turbo-alternators of the most modern and up-to-date construction, having the highest economy obtainable.

Three-phase current will be generated at a pressure of 5 500 volts between phases, at a periodicity of 25 cycles per second. This will be distributed in three ways:—

(1) Partly at the pressure of generation to large power consumers and substations in the neighbourhood of each generating station.
(2) Partly at a pressure of 33 000 volts to outlying centres, where it will be transformed down to a convenient voltage for distribution.
(3) Partly at a pressure of 66 000 volts by means of overhead transmission lines to the more remote portions of the District, where it will be transformed down and distributed in detail.

By centralizing the generation of electricity in this way and locating the stations as near as possible to the bulk of the demand, advantage can be taken of the very low cost of production, and the cost of transmission is reduced to a minimum.

Estimates have been prepared of the results to be expected from the arrangement I have described, based upon the anticipated growth of the demand in the District.

It has been assumed that the demand will grow at a slightly greater rate than it did before the war.

The demand in 1920 was 92 650 kW. A demand of 150 000 kW is expected in 1925, and of 214 250 kW in 1930.

The corresponding outputs will be:—

Year	Million Units	Load Factor
		Per cent
1920	199·08	24·6
1925	359·9	27·5
1930	562·7	30·0

This estimate is exclusive of any demand that may be required for railway traction purposes. Such a demand may very well reach 60 000 kW within a radius of 50 miles from Birmingham.

The thermal efficiencies of the existing stations in the District vary between 5·5 per cent for the smaller stations and 10·7 per cent for the larger stations. The thermal efficiency of the new capital stations will be approximately 16·5 per cent.

The bulk of the load will be dealt with in the new stations, whilst the older stations will be utilized to meet the short-hour peak-load demand and stand-by purposes.

In this way it is estimated that a very large saving in coal over what would be consumed if the present rate of consumption were continued will be effected.

Based on the outputs I have indicated, the figures are as follows:—

In 1925, 458 000 tons of coal will be consumed, equivalent to a total saving of 118 200 tons.
In 1930, 655 000 tons will be consumed, equivalent to a total saving of 256 700 tons.

The cost of generation to-day is about 0·96d. per unit.

The cost in 1925 will be about 0·44d. per unit, or a reduction of 54 per cent on the present cost.

In 1930 the cost will be about 0·33d. per unit, or a reduction of 65·7 per cent on the present cost.

Such a result must have a very material effect in cheapening the cost of electricity to the consumer, this being the real object of the present development that is taking place in the country.

Nechells Power Station.

A short description of the leading features of the Nechells power station may be of interest.

The station is laid out for an ultimate capacity of 105 000 kW, comprising seven 15 000-kW turbo-alternator sets. Three of these are being installed at present; the first should be available early in 1922.

The boilers work at a pressure of 325 lb. per square inch, and the total temperature of the steam is 700° F.

The surface condensers are designed to maintain a vacuum of 28 inches, and the circulating water is cooled by a system of wooden cooling towers erected over ferro-concrete reservoirs.

The switchgear control has been sectionalized as far as possible by means of reactances, chiefly with a view to limiting the heavy strains that the switches are called upon to meet when emergencies occur.

I have mentioned only the leading features, to show the altered conditions that obtain in the modern capital stations now being designed to ensure the greatest economy in operation, in regard to both thermal performances and reduced labour and capital costs.

WESTERN CENTRE: CHAIRMAN'S ADDRESS

By A. C. MacWhirter, Member.

(Abstract *of Address delivered at* Cardiff, *7th November*, 1921.)

This year should be a memorable one in the history of the Institution, for it celebrates its 50th anniversary. Starting in May, 1871, with a membership of 66, it has grown steadily until to-day its membership is nearly 10 000. In this, our Jubilee year, great honours have been conferred. A Royal Charter of Incorporation has been granted, and His Majesty the King has been graciously pleased to intimate his willingness to become Patron of the Institution, an honour of which we are all, I am sure, justly proud. Our very best thanks are due to Mr. Ll. B. Atkinson and the Members of the Council who were instrumental in carrying the work through.

The Western Centre.

In 1912, when the Western Centre was formed, its membership was 213, and this has now reached the very satisfactory total of 421. The Centre is yearly increasing its activities, but the very successful meetings held at towns other than Cardiff or Bristol have led me to think that still more could be done to further the aims of the Institution.

I would suggest the division of the Centre into two parts, with the Bristol Channel and the River Severn as a dividing line. This would allow a greater number of meetings to be held in the West of England and Wales, and would certainly stimulate local interest in the Institution meetings. The question of finance would have to be carefully considered, but I feel that any increase in expenditure would soon be compensated by the revenue resulting from increased membership.

If the suggestion were carried out the membership of the two divisions would be as shown in the tables in the next column.

I submit this suggestion for careful consideration and criticism.

North of the Bristol Channel.

	Members	Associate Members	Associates	Students	Graduates	Total
Brecknockshire ..	—	—	—	—	—	—
Cardiganshire	—	1	—	—	—	1
Carmarthenshire ..	1	2	—	3	2	8
Glamorganshire ..	30	90	3	18	21	162
Herefordshire	—	1	1	—	1	3
Monmouthshire ..	1	20	—	1	8	30
Pembrokeshire ..	1	2	—	1	5	9
Radnorshire	—	—	—	—	—	—
	33	116	4	23	37	213

South of the Bristol Channel.

	Members	Associate Members	Associates	Students	Graduates	Total
Bristol	13	28	1	7	18	67
Cornwall	1	7	—	—	1	9
Devon	13	30	1	5	6	55
Dorset	2	4	2	1	2	11
Gloucestershire	5	6	2	1	6	20
Somerset	6	16	—	2	6	30
Wiltshire	4	4	—	1	7	16
	44	95	6	17	46	208

Labour.

During the war all business developments other than those strictly necessary for war purposes were suspended. For this reason the electrical industry experienced unprecedented prosperity until the end of 1920.

Financial difficulties, the inevitable aftermath of war, in conjunction with the coal strike of this year, have changed the whole trade outlook. The problem of unemployment has become alarmingly serious and there is still very little sign of improvement. We are told that the reason for the change is the present high cost of production and the unfavourable exchange, which allow our foreign competitors to undercut us in the world's markets.

Although the recent coal strike lasted only 13 weeks, the results are far-reaching. The financial stability of Great Britain has been shaken, and the establishment of trade on a sound economic basis has been delayed. The wages lost by the miners are irrecoverable, and the results of this strike have been as disastrous to the miners themselves as to the other classes of the community. Surely it is not beyond the wit of man to devise a scheme of arbitration which will avoid these trade upheavals.

Wages, in many industries, are regulated by the Board of Trade returns. It is a hard economic fact, however, that the cost of living will not fall until wages are decreased. The alternative to decreased wages is increased production, and I am of the opinion that if we are to maintain our position as an export nation we must increase the number of our daily hours of work. We shall be forced to return to the pre-war hours of labour, and I am sure that the total production can be doubled with little extra effort.

The argument advanced by the Labour Party, that "the reduction in hours of work, with the resultant increase in the hours of recreation, would give increased production," has not been borne out in practice. The reverse has been the result. We must not wholly blame the workers for their "ca' canny" policy, for they are often led by extremists who are put into power by a minority. It is an acknowledged fact that the majority of the more intelligent and highly skilled craftsmen take little or no interest in the affairs of their unions, with the result that these organizations are not conducted in a manner beneficial to the industry generally and the workers in particular. A much broader outlook is required in trade-union matters, and it is the duty of employers and all others in authority over labour to encourage their good workers to interest themselves in the affairs of their union to a much greater extent than they have done in the past.

How can the present attitude of labour be changed? Many systems, such as bonus, profit-sharing and management-sharing, have been tried with varying success. But no scheme will succeed until the workers realize that the interests of the employers and the employed are identical. Both classes must work together for the general good. Neither master nor man should demand an undue proportion of the profits of his industry. When this principle is generally accepted we shall be able to produce goods at a reasonable price for the benefit of the community as a whole.

Industrial Relations.

The promotion of good feeling and mutual confidence between employers and employed is a question which has been exercising the minds of those—and they include almost all of us—who have been brought into close contact with it. From the treatment of the subject in the Press one might imagine that it had been forced into prominence only during the war. Those of us whose knowledge and industrial experience go back beyond 1914 will probably agree that the war did little more than hasten the study of the various aspects of this problem.

The question of industrial relations is always with us. There are, and always have been, extremists on either side. There are employers, and others who are not employers, who believe that all workers should be compelled to work, whenever and wherever required, for fixed wages, and that they should be content to be turned off and left to exist as best they can when not required for the production of goods.

On the other side there are those who would make an equal division of the wealth of the world, giving to the most corrupt and incompetent an equal voice with the really hard worker in the control of our affairs.

With both classes of extremists the desire is to be "top dog." There is a lack of any spirit of confidence, and it is this spirit above all others that is required to influence the situation for good.

It is useless to talk about the "inevitable conflict between capital and labour," or of a "class war." The advocates of these policies always forget to ask themselves what the situation will be after the "inevitable conflict or class war" has been fought and won or lost. The answer is, that the problems which seem eternal will still exist, and their solution will be more urgent than ever.

The post-war industrial situation seems more chaotic than the war itself. This is due only to the complexity of the matter and the necessity for continual adjustment. There can never be any finality in this matter.

The Whitley Report has suggested a way, and I am pleased to see so many industries adopting the scheme of Joint Industrial Councils. From my own experience of District and National Councils for the Electrical Contracting Trade the feeling of confidence is growing stronger at each meeting, and a very marked difference can be observed in the attitude of even the extremists. The Whitley scheme is good, but in my opinion it does not go far enough, for we have had instances of the findings of one District Council entirely upsetting those of another Council in the same district.

About 3 years ago the local branch of the Electrical Contractors' Association put forward a scheme to overcome this difficulty, but it fell through from lack of general support. As a result, each trade or branch of trade settled its own affairs (such as wages) without any consideration as to what had been done by other Councils in the district.

Registration of Contractors.

The contracting section is an important part of our industry, and established firms should be supported

in their endeavour to work against those who have nothing at stake, and yet style themselves Electrical Contractors.

The Electrical Contractors' Association is endeavouring to raise the contracting trades to a higher standard, but the assistance of all who place orders for contracting work is required to bring this about. Only responsible firms should be employed. It is not in the best interests of the industry to engage a contractor simply because his price is lower than that for which competent firms can carry out the work. Generally it will be found that the contractor in business on his own account has no administration charges, and "labour cost" he calls "profit." The Association now accepts as members only firms who are competent to carry out work satisfactorily, and whose work the Association is prepared to guarantee.

The Association is hopeful that in the near future the compulsory registration of contractors will be an accomplished fact, and I believe that the Institution would welcome and support such a reform. The Institution would possibly be the body authorized to issue, by examination, the necessary licence.

In reviewing the position of the contractors, it is necessary to consider the question of supply authorities who possess trading powers. Many Municipal Engineers secure orders by representing to the consumers that their department can do the work more cheaply and more efficiently than an outside contractor. While it is often the case that the department can undertake the work for a low price, it must not be assumed that this is a proof of efficiency. More often it is merely a matter of accounting. Expenses are so apportioned among the various departments that the contracting department appears to be flourishing, whereas in fact it is making a loss which is borne by the other departments. Thus the contracting loss has to be borne indirectly by the rate-payers.

I am absolutely opposed to municipal trading and I cannot understand why the municipalities should be allowed to compete with the rate-payers. It is my opinion that if Municipal Engineers were to exert all their energy in providing cheap power, they would find their time fully occupied.

Commercial Development.

This is a matter which is exercising the minds of many of us just now. The commercial development of electricity during the past decade has been one of the wonders of our time. Prior to that time our problem was to harness and use the power which had been discovered. Scientific principles were mainly involved. To-day we are chiefly concerned with the economic aspect of the question.

Success can be achieved only by adjusting and co-ordinating all the forces in the Electrical Industry with a view to fashioning an efficient business-getting machine. There is no doubt that such a machine is absolutely necessary for our future progress.

In one of the electrical journals the views of supply authorities, manufacturers, wholesalers, contractors and others, on this subject are being given, and all appear to be more or less in agreement.

The present system, or lack of system, under which few manufacturers consider any interests other than their own, is largely responsible for the present discontent which is manifest in every direction. The manufacturers should meet and discuss affairs with the wholesalers, retailers and large users, and should invite suggestions in regard to the production of efficient apparatus at a price which should tempt the user to purchase.

The supply authority should devote its attention so to reduce the cost of power as to make it a necessity to every consumer on the mains. They should evolve a scheme, either alone or in conjunction with manufacturers and contractors, to let out on hire the more expensive apparatus.

The wholesaler should carry sufficient stock for all the usual requirements, and keep in touch with the latest and best appliances. These he can introduce to the retailer and contractor, who in turn should assist by interesting the user.

Many contractors do not realize how much they can do towards the development not only of their own business but of the whole Electrical Trade. It should be an essential part of a contractor's duty to interest the consumer in the manifold uses to which electrical power may be put. Few consumers make the maximum use of their power and lighting installations, simply because they do not realize the possibilities of electricity. By pointing out new uses, the contractor will help the consumer in the efficient running of his business; at the same time he will be promoting the sale of additional appliances, with consequent benefit to the manufacturers, the wholesaler, and himself.

Some people may ask how all this affects them. My reply is that the commercial development of electricity is of paramount importance to every Electrical Engineer. We, as an Institution composed of every branch of the profession, should take a keen interest in the subject, and, if possible, give every assistance to the many problems which impede the progress of our industry.

Apprenticeship Training.

The technical training of apprentices in Electrical Engineering is one of the urgent problems of the present time. The pre-war method of restricting the period of instruction to the evening hours is generally recognized as quite unsuitable for the average boy, although good work has been done by lads of exceptional ability. Apprentices should receive a part-time training during the day, of not less than one whole afternoon a week, devoted entirely to technical instruction.

With the assistance of our Technical College, part-time training was started in Cardiff last session. Under this scheme lads in their first and second years attend one whole day each week at the College. They are taught the theoretical and technical side of their trade concurrently with the practical side. The results have been highly satisfactory, and I am hopeful that this year special lectures on economics and politics will be

given to apprentices. By politics I do not mean, of course, the politics of the professional politicians.

It is the duty of every employer to see that only those boys of proper education and physique enter the Electrical Profession. This will ensure that our industry will be composed of well-trained craftsmen who will do us credit—craftsmen of the old-fashioned sort who really love their work. We must not forget that these boys will some day form part of their trade union and possibly become leaders; therefore, by teaching them to understand the laws of supply and demand, we shall make them better able to control and keep the extremists in check. At the present time there are many lads in the Electrical Industry who are wholly unsuited to follow their occupation. These in time must degenerate into the nondescript or semi-skilled workers so much in evidence in some sections of our industry, who retard the progress of our profession.

There is another matter with regard to apprentices to which I should like to draw attention. Many firms —particularly those engaged in repetition work— flood their factories with apprentices and employ proportionately few journeymen. This is done, of course, to keep down production costs. It is, however, impossible for these firms to absorb all these lads when they have completed their apprenticeships. They are thus thrown on the world with a very inferior training, for it is well known that factory-trained apprentices do not receive an all-round experience.

I think that this state of things should be made impossible, and that the proportion of men to apprentices in each trade should be regulated.

Ability of Workers.

I feel that all workers should be required to pass examinations in the various branches of their trade, and that certificates of their capabilities should be issued. This would allow their remuneration to be graded according to the degree of efficiency.

Electrical contractors, to an even greater extent than manufacturers, are often obliged to employ inefficient labour. The result is that contractors suffer a loss, not only in money but in reputation and prestige.

In addition to some guarantee of more efficient labour we must have some means of protecting from abuse the designation "Electrical Contractor." At present anyone can call himself an electrical contractor, even though he only possesses half-a-dozen tools and has neither capital nor knowledge of the work.

Standardization.

The carrying out of repairs to electrical machinery has brought me into close contact with the manufacturing side of our industry, and a few remarks on my personal experience may not be out of place here.

There are still some manufacturers whose products are far from perfect and invariably have a very short and troublesome life. First-class firms also produce at times machines which are badly designed and generally open to great improvement; but I find that most designers are so autocratic, not to say self-important, that to suggest, even tentatively, any improvement in their designs is regarded as a personal insult.

I feel that all designers should take, as part of their training, a course which I would entitle "Electrical Machinery under Working Conditions." They would learn much to their advantage, as test-bed conditions are rarely obtainable in practice. For instance, a motor is designed to take full load for a certain time with a certain increase in temperature. The same motor may be passed into service, possibly in a foundry or flour mill, and in a few weeks the air ducts in the armature or rotor become partially or completely blocked, causing overheating which entirely upsets the test-bed figures. In my opinion too much reliance is placed on the cooling effect of circulating air, and designers in their desire to reduce costs approach very closely the critical point of safety.

The British Engineering Standards Association have been, and are, doing excellent work in certain branches of standardization, but I venture to suggest that the time has now come to standardize certain dimensions of electric motors and generators, particularly in the small and medium sizes. This would enable one make of machine of a certain size frame to be replaced by any other make; for instance, a motor driving a pump or other machinery on a combined bedplate can never be replaced by a standard motor of another make unless by some makeshift arrangement. This is a constant source of irritation to the engineer-in-charge.

My suggestion is to standardize the following dimensions:—

(*a*) Centres of foundation bolts.
(*b*) Height of shaft centre to base.
(*c*) Distance of bolting-down holes to end of shaft.
(*d*) Diameter of shaft and size of keyway.
(*e*) Length of shaft from bearing housing.

These dimensions would require to be fairly liberal to permit any development in design. The standardization of these dimensions would possibly affect the artistic appearance of the machine, but the benefits derived would more than compensate for this.

There is little hope that manufacturers will voluntarily support such an arrangement, since it would involve alterations to existing patterns, jigs, gauges, etc. The reform could be brought about only by users and consulting engineers insisting that motors must be supplied in accordance with the standards for the particular class of machinery. Then, and only then, will the manufacturers be brought into line.

The multiplicity in types of carbon brushes and brush-holders is another continual source of annoyance and expense, particularly in the case of large installations where it is necessary to stock spares. This is due to the variety of shapes, grades and connectors used by different manufacturers of electrical machinery. I am informed by makers of carbon brushes that there are about 100 grades of brushes, while the types, sizes and fittings number about 1 000. These figures give some idea of the difficulties with which the brush manufacturers have to contend. Although they usually carry stocks of over 300 types of brushes in general

use, they can execute only about 40 to 50 per cent of orders from stock.

I am pleased to learn that a Sub-Committee of the British Engineering Standards Association, after 3 years of work, are about to recommend a set of standard sizes, fittings and tolerances for use. In the matter of grades, however, it has been impossible to arrive at a decision. The Report, when published, will be most interesting and useful.

Standardization could be successfully carried much further than is at present attempted. What is more unsightly than a beautifully-panelled main switchboard which has had an extension fitted by another maker, with the result that the switches, instruments, circuit breakers, etc., are out of line with the original design?

I think it is quite possible to standardize the size of main panels and sub-panels, their drillings, the centre line of switches, instruments, circuit breakers, etc., without materially affecting the apparatus behind the switchboard. Such standardization would ultimately assist British Manufacturers. The designer should be required to design his gear so that it could be connected with similar gear of another make.

The standard outside sizes must, however, be liberal enough not to restrict the space required for improvement in design.

Industrial Research.

Many of the large manufacturers have a separate research department, in which various troubles experienced in connection with electrical machinery are investigated. In these research departments new ideas with reference to design are tested to find out if they are possible in practice.

Under existing conditions of industry and finance, it seems desirable to reduce costs by placing this research work under the control of a central authority. It is a well-known fact that, in many cases, inventors are working along the same lines at the same time. Surely it is possible to have such a central authority as suggested so that manufacturers could notify this authority of their new ideas in design, and also of the various troubles which they experience with their manufactures. This arrangement would allow the central authority to advise the various manufacturers as to the work undertaken by the various research departments, and a great deal of overlapping might thus be avoided.

As a case in point, difficulties have been experienced by nearly all manufacturers of large turbo-alternators. This has required a great deal of pioneer work in the research departments of various manufacturers, and obviously there has been a great deal of overlapping. I feel sure that, if there had been a central clearing house for research, various manufacturers could have divided up the whole problem and reached a solution much more quickly and at a greatly reduced cost.

The design of electrical machinery has now reached a stage when there are no secrets of any importance except in small detail, and if we are to compete with foreign markets and reduce costs it is imperative that manufacturers should pool their knowledge. This, I consider, can best be done by means of a central research authority.

Conclusion.

I have confined myself in this Address to a discussion of the labour and administrative aspects of our business. I have done so purposely because we, in common with other industries, are undoubtedly passing through the most critical period in our experience. Many well-informed critics are of opinion that the present depression in the trade of this country will continue and possibly increase during the next 3 or 4 years. I do not believe that anything of the kind is inevitable in our business, provided we can institute a new and better spirit in our work. As I have indicated, employers must strain every nerve towards the highest efficiency in the organization of their businesses. They must be content with reasonable profits. Furthermore, they must, by wisdom and moderation, seek to recapture the loyalty of their workers.

The worker, on his part, must get rid of that suspicion of his employer which has recently driven him into short-sighted and perilous courses.

Workers and employers, we are all in the same boat. We must sink or swim together. This, I think, is being gradually realized by both sides, and I am optimistic enough to hope that, before my term of office has expired, we shall have passed the bottom of the curve of trade depression and be well on our way towards a lasting period of peace and plenty.

SCOTTISH CENTRE: CHAIRMAN'S ADDRESS

By E. T. Goslin, Member.

(Abstract *of Address delivered at* Glasgow, *8th November*, 1921.)

Rates and Finance.

When considering what subject I should take for my Address, I endeavoured to find one which I thought might be of some interest to the majority of those connected with our profession in Scotland, and, at the same time, one that I could handle with at least a little inside knowledge. The subject I have selected is—Rates and Finance. My decision to choose that topic was considerably influenced by a newspaper cutting from an electrical journal, sent to me by a candid friend. The wording was as follows: "We have been doing the finest job of technical work that the world ever saw, but as merchants we in the central station industry have been about the worst."

We certainly have been indifferent merchants. We have a product to sell which is in general demand, but, notwithstanding, we have failed to make adequate profits out of our trading, and in some cases have made a dead loss.

No merchant would manufacture an article which would cost him more than he could purchase it for in the open market.

Where a manufacturer having built and equipped an efficient factory producing goods at a marketable cost has, after a time, under consideration an extension to his factory, he would not expend further capital on such an extension if he found that the added charges for the extra capital required brought his works costs above the price at which he could purchase the article in the open market. This phase of bad marketing must frequently come under the notice of the Electricity Commissioners, but, in spite of all wire-pulling, political influence and other opposition, inefficient production of electrical energy will be stamped out, and the unsuitable stations will go out of the business. The Corporation of Glasgow were among the first to scrap their older power stations. Justification for this bold step will, I am sure, soon make itself apparent.

To many of those trained as engineers, the engineering side of an electricity supply concern is more interesting than the purely commercial or business portion and, in consequence, it tends to claim an undue share of attention. Engineering becomes too much of a hobby: everything of the best, almost regardless of the cost, is wanted; in fact, some engineers are becoming too expensive in their tastes. Most of us have now learned the necessary lesson, but the industry is still suffering from a neglect of sound finance.

Finance cannot be separated from rates. I believe that nearly every undertaking supplying large power consumers under long-period contracts is suffering from rash contracts, more especially flat-rate contracts, made without a sufficient knowledge or, at any rate, without sufficient investigation as to the cost of such supplies. Increasing the output is one of the best ways to decrease costs, but accepting contracts at unreasonably cheap rates, with a view to increasing the output, will not have the desired effect. Every consumer's rate should show a margin of profit.

It is manifestly unjust to make the small consumer pay for the losses on the large consumer: that this is being done is beyond doubt.

In the West of Scotland we have two large electricity supply concerns—approximately of the same size—the municipal supply of Glasgow and a company supply by the Clyde Valley Electrical Power Company. Owing to the Company's territorial ramifications, it is unfortunate that its activities rarely obtain the recognition in the Press which the importance of its public utility services demands. I am very pleased to say that the two great undertakings I have mentioned work together in perfect harmony.

The rates charged by these two undertakings are not similar, and cannot or should not be so. Their obligations are different. Those of Glasgow are well known, but ignorance would appear to exist as to the duties and operations of a power company.

The Clyde Valley Electrical Power Act, 1901, authorizes the company to supply energy in its area under the following limitations, the clause reading:—

(1) Unless otherwise expressly provided by this Act energy shall be supplied under this Act only:—

(*a*) In bulk to authorized distributors; or
(*b*) For providing power to any person.

The Act also limits the supply of lighting to 20 per cent of the total energy supplied to the consumer.

The Company under certain specified conditions must supply on demand all authorized distributors, and must supply energy to any person within its area. Added to these restrictions are the maximum-price clause and the clause which limits the relation between price and dividend. I am glad to say that this price and dividend clause does not trouble the Clyde Valley Company. The maximum price it may charge is 3d. and the maximum dividend it may pay is 8 per cent. If, however, the charges are lower than "an average standard price"—fixed by the Act at 2½d.—the dividend may be increased by ¼ per cent for every 1¼ per cent by which the average price charged is below the standard price. Last year the Clyde Valley Company's average price was 1·26d., so that the *permissible* dividend for that year is automatically fixed at nearly

18 per cent—7½ per cent was actually paid. The Clyde Valley Company's area covers 746 square miles, extending from Loch Lomond in the West to Shotts in the East, and from Milngavie and Kirkintilloch in the North to Lanark in the South, and embraces a diversity in industry which falls to the lot of only a few supply concerns. This diversity covers the coal, steel, and shipbuilding industries, and in addition many other manufacturing processes which go to make up the Company's high load factor of 42 per cent.

Customers are often far apart, and a new customer may entail an extension of miles to the existing distribution system. Under these conditions what protection has the Power Company for its capital outlay ? Long agreements can be negotiated with the customer, fixing, amongst other matters, a minimum charge per quarter, giving a return of at least 20 per cent on the capital outlay on the cost of the service only : in other words, if the service cost was £1 000, the customer would be required to guarantee that his quarterly bill would not be less than £50. Luckily for power companies, this minimum charge is seldom called for, as the customer's bills usually exceed the amount of the guarantee. The minimum charge is not a paying proposition to either company or consumer.

It will be seen that a power company cannot choose its customers ; the cost of money must not influence its decisions ; and it must at all times be prepared to expend further capital in carrying out its duties to the public.

If investors do not receive a reasonable return for the money they have invested, there will be no inducement for further investment. Money will become more and more difficult to obtain, and the undertaking will gradually become less efficient ; costs will rise ; rates will follow ; and it will soon find itself in difficulties, the shareholders and consumers both suffering from the effects of bad finance.

The shareholders' and consumers' interests are one : sound finance means a sound supply, and to obtain both of these ideals sound rates must be quoted.

Rates may be divided into two classes, i.e. meter rates and demand rates, which again can be sub-divided, the most prevalent forms being :—

Straight-line meter rate ;
Step meter rate ; and
Block meter rate ;

and, for the " demand " rate :—

Flat demand ;
" Wright " demand ;
" Hopkinson " demand ; and
Three-charge rate.

The straight-line meter rate is constant and does not vary in accordance with the units consumed. The step and the block meter rates take into account the quantity consumed, the charges being reduced in steps or blocks.

The flat demand is a constant rate, or rent, based upon the size of the consumer's installation It may be compared with a domestic water rate.

The Wright demand is based on the consumer's use of his maximum demand, a reduced price being charged after so many hours' use of this maximum demand.

The Hopkinson method consists of a charge or rent based upon the customer's demand, plus a charge for energy used, the latter charge being a straight-line, or step or block meter rate.

The three-charge rate consists of a " customer " charge, a " demand " charge, and an " energy " charge.

It is obvious that with long-term agreements the rates quoted for the period of the agreement must have some flexibility. This can be taken care of by sliding-scale coal and wages clauses.

It was in 1882 that Dr. John Hopkinson first put forward his suggestions regarding a sounder method than the flat meter rate of charging electricity consumers. He enunciated the principle of making the demand the main feature in making up the rate chargeable. Some 10 years later he read a paper on the subject showing that his previously expressed views still held good. His considered opinion was that, to enable a just rate to be fixed for all classes of consumers, the maximum demand charge, plus a charge for energy consumed, was the only solution. It is the combination of this " demand " and " energy " charge that brings into account the load factor—the first step, and a very important one, towards charging the customer in accordance with the " quality " of his custom. I shall mention later other points which require consideration when the " quality " of the consumers' demand on the plant of the electricity supply undertaking is examined.

Since Dr. Hopkinson's original proposals were published, scores of papers have been read on this question of rates, dozens of more or less new suggestions have been put forward in attempts to improve the methods of charging, but the Hopkinson method still survives in one or other of its various forms, and is generally accepted as being the best. It must not be assumed that, because by far the greater number of customers in this country are charged solely by the kilowatt-hours they consume, this flat rate is not founded on the Hopkinson demand system. The habits of the smaller consumer have become known to the rate-maker. The number of lamps he burns at the same time, and the number of hours he burns these lamps, together with his use of heating, cooking or cleaning apparatus, etc., are approximately known. His demand and load factor are known, but the rate-maker in fixing his rates adds a considerable percentage for the extra cost of handling these smaller consumers, and probably adds a little more for " contingencies " in case he has under-estimated something or other, and also because he knows he will be able to get the rate quoted. Electric light has come into its own at last—at any price it is cheap.

In fixing the rates for the larger consumer, great care must be taken to ensure that the " quality " of the demand is taken into account. Each consumer must bear his just proportion.

Two consumers, next-door neighbours in the same business, and working the same hours, may be widely apart in the " quality " of their demand. How are we to penalize the one and reward the other ? The

Hopkinson demand method with the addition of a power factor clause will meet the case, if the demand is taken in kilowatts. There is not much trouble entailed in getting the consumer to understand the maximum-demand system or the meaning of load factor. I admit there is difficulty in explaining the power factor charge to a non-technical person, but if the demand is taken in kilovolt-amperes the power factor clause disappears. I, personally, shall be very glad when it does so.

There is a feeling of uneasiness amongst a section of the public regarding the rates charged by power companies. I put this down to two causes :—

(1) Supposed monopoly, and consequently high rates ; and

(2) Supposed preferential rates.

It is true that the power company is the sole authorized undertaker to sell power in a certain specified area, but an electricity undertaking has powerful competition from gas interests and private installations in its area. There is nothing to prevent any works from putting down their own generating plant. The rates quoted by the power company must, consequently, be able to meet this competition.

It is generally supposed that a dividend-paying undertaking must of necessity charge more than a municipal one, but this supposition is incorrect, as will be seen by comparing the receipts per unit sold of the largest municipal and company undertaking in this district, the Glasgow Corporation and the Clyde Valley Company. The average price per unit sold for the years ending May 1920 and 1921 were as follows :—

	Company	*Corporation*
1920	1·2694d.	1·5798d.
1921	1·46d.	2·04d.

Referring to the question of preferential rates, I fully appreciate the consumer's feeling of annoyance if he suspects that someone has made a better bargain than he has made. I blame both companies and municipalities for the spread of this feeling. Rates in the past have been kept too secret—another case of bad marketing. Let us put the goods we have for sale in our window and attach to them a ticket with the price marked in large figures and so let the passer-by know what he has to pay should he require the goods, and, what is almost as important, what his neighbour will have to pay for the same class of article. It may be that some of the goods displayed, although they look the same, have different prices marked on the ticket. The prospective customer will probably at once assume that this is due to "quality." Perhaps he may ask the reason for the difference in price, and, on being enlightened on the "quality" point, go on his way contentedly. Our business should be conducted on these same lines. Secrecy in connection with rates is an error of policy. Both the Company with which I am associated and the Glasgow Corporation issue their rate schedules to anyone who cares to ask for them, and, what is of more importance, the rates given in the schedules are adhered to.

The rates quoted under existing conditions may appear to the consumers to be high. I have not the least doubt that the rates now quoted have reached the high-water mark ; they will be gradually reduced, they must be reduced, but a time-lag is necessary. Generally speaking, rates were not advanced during the period of the war until after an advance was economically long overdue. This is an unfortunate fact that many electricity undertakings have to face. I sincerely trust that no panic reduction will be made.

I was much interested in an article in the electrical Press, giving particulars and comparisons of generating costs for the years 1914 and 1920. The increase in the cost of production was shown to vary from 110 per cent to 175 per cent, and the cost of new plant to produce and distribute electricity was no less than 225 per cent higher than it was in pre-war days. It is obvious that these huge increases have to be paid for.

It may seem hardly necessary to call attention to the main conditions governing the fixing of rates, but, from letters I have seen published in the technical Press, and also from statements made by people who ought to know better, these conditions are sometimes entirely overlooked. The rates must be fixed so that income and expenditure balance each other. In expenditure I include a reasonable payment to reserve funds, plus a reasonable dividend to the ordinary shareholders in the case of a company undertaking. If I were asked what I consider "a reasonable ordinary dividend" to be, I should not hesitate to state my personal views, which are that the ordinary dividend should be not less than sufficient to keep the market price of the ordinary shares at par. The dividend to be aimed at may be anything from 5 per cent to 10 per cent, or even 15 per cent, depending on the state of the money market. At the present time a 10 per cent dividend might be required to keep up the share value, as against something like 5 per cent for pre-war times.

Summarized broadly, the conditions which control the selling price of electricity are :—

(1) Capital cost of scheme.
(2) Running charge of scheme.
(3) Load factor.
(4) Power factor.
(5) Diversity factor.
(6) Area of supply.
(7) Type of supply (a.c. or d.c.).
(8) Population density per square mile of supply area.
(9) Nature of the industries within the supply area.

The first essential is to keep the capital cost of the scheme as low as possible. This can be done only by taking long views, obtaining the best value for capital expended, and legislating for the best up-to-date engineering practice at moderate cost. The art of power production progresses so rapidly that it becomes unwise to make provision for a long economic life for plant. A typical instance of this is the turbo-generator, and we can all call to mind instances where rapid progress in design has rendered obsolete costly plant within half its estimated life. We must keep carefully in view this rapid obsolescence and not design our engineering schemes in a manner which suggests that finality has been reached.

The first consideration in any electricity supply concern should be the cost of the finished product, i.e. the selling price of the kilowatt-hour. The merits of any scheme which promises a reduced running charge with added capital expenditure should be carefully weighed against the increased capital charge on the unit. In this connection all departures from standard practice involving the use of extreme steam and electrical pressures should be carefully considered.

Load factor, more than any other condition, influences the selling price of the kilowatt-hour.

All means should be taken, therefore, to induce the consumer to extend the period of his supply and benefit by the reduced rate. Additional inducements to extend the supply period may be given by altering the form of the rate charged; for instance, by increasing the maximum demand charge whilst reducing the charge for energy supplied.

A further corrective to the rate charge is introduced by condition (4), power factor.

Until recently, supply authorities tolerated the conditions introduced by low power factor. Lately, however, there has been a general awakening to the losses incurred and the unremunerative return on the increased capital expenditure introduced by this undesirable condition, a condition which is quite unfair to the consumer with a good power factor, who has to pay a part of the extra cost caused by the consumer with a low power factor. Low power factor increases the capital cost of the system, mainly in the distribution system, and, in a lesser degree, in the power station. For example, between unity power factor and a power factor of 0·7 an increased investment in cable of 20 per cent would be required for the lower power factor. Static transformers operating on the lower power factor would demand an increased expenditure of 30 per cent, and the cost of turbo-alternator plant would be approximately 12 per cent higher. Operating costs also are affected, alternator efficiencies are lowered, losses in the distribution system are increased, and static transformer efficiencies are reduced. A further direct loss is sustained through the impaired voltage regulation available at the consumer's terminals. In this latter case valuable energy is lost as heat in the distribution system, which heat should be available as increased average pressure at the consumer's terminals, with a greater revenue return. We see, therefore, that low power factor increases the capital charges on the unit by a certain figure, and the running cost is likewise increased. In cases where we have a compound charge, i.e. a maximum demand and a running charge, the correct method of assessing the charge for power factor would be to have a plus or minus correction on the maximum demand rate, in proportion to the increased capital expenditure entailed by the power factor. A further correction might also be made on the running charge, in accordance with the increased inefficiencies introduced by the power factor, but, personally, I consider the extra on the "demand" to be sufficient. On power-supply systems where accurate records are kept, these proportionate charges should not be difficult to assess. Unfortunately, however, when we come to the consumer, difficulties present themselves. A method of charging which is not readily understood by the consumer breeds a feeling of distrust, which is not in the true interests of power supply. From amongst several systems of charging on a kilovolt-ampere basis I would mention three typical methods:—

Kilovolt-amperes of maximum demand.
Kilowatts of maximum demand, plus kilovolt-amperes consumed.
Kilowatts of maximum demand, plus or minus power factor, plus kilowatt-hours consumed.

The first and second methods of charging are straightforward and commend themselves to the consumer on account of their simplicity, as they are equivalent to the ampere-hour charge on a direct-current circuit, but a direct-reading kilovolt-ampere meter is urgently needed. The third method involves an explanation of power factor, and the difficulty of conveying a true understanding to a non-technical person has to be experienced to be understood. Referring to the charge on the kilovolt-ampere basis, while this is simple we should ask ourselves whether it is fair. The charge does not differentiate between leading and lagging power factor, and it must be conceded that a consumer who has a leading power factor and thus relieves the distribution system of some other consumer's lagging current deserves consideration.

Coming now to the alternative method of charging, i.e. the power-factor rebate, there are two ways in which we can apply this. First, we can select a certain power factor as standard, and increase or decrease the standard charge by the ratio of the standard power factor to that obtained. It is necessary to proceed cautiously, however, in applying this charge. If the rebate is given on the average power factor obtained, cases may arise where the average power factor may be such a leading one as to constitute a serious loss to the power-supply authority. This can be shown by the following typical example, and the assumptions are:—

Power factor of 0·8 as standard.
Consumer with a load factor of 20 per cent.
Natural power factor of 0·7, raised to unity by means of static condensers.
Maximum demand rate of £5 per annum per kilowatt.
Energy charge of 0·7d. per kilowatt-hour.
Condensers left in circuit continuously for the purpose of phase-advancing.

These conditions give an average leading power factor of 0·25, the consumer benefiting by a combined charge of 0·63d., which is lower than the energy charge of 0·7d. per kilowatt-hour. It becomes necessary, therefore, to preserve the energy charge, which represents the cost of production. This may be accomplished by increasing or decreasing the maximum demand rate of £5 according to the power factor, and leaving the energy rate unimpaired. In this latter case the rate corresponding to the previously mentioned power factor of 0·25 would become 1·01d. per kilowatt-hour.

I wish to confine my closing remarks to the all-important problems before the country just now—un-

employment and bad trade. Electricity undertakings can help to overcome both. Cheaper production of electricity means cheaper rates to the consumer, which will in turn bring about lower manufacturing costs and improved trade, with a consequent greater demand for labour. I appeal to all electricity undertakings to help. The co-operation of supply authorities is necessary to ensure that the main object of the Electricity (Supply) Act 1919—"To ensure the provision of a cheap and abundant supply"—may be obtained. Without co-operation cheap supplies cannot be given.

It is a matter of extreme regret to me and, I feel sure, to all of us, that, since the passing of that Act, an atmosphere of doubt and suspicion, which does not tend to bring about the desired co-operation, has to some extent arisen in certain quarters; in fact, this aspect of distrust is becoming a disease—a nervous disease. Nervous diseases are sometimes hard to diagnose, but before a cure can be effected we must get at the true nature and seat of the trouble.

I have found it impossible to write my diagnosis without coining a compound word "neuropolitiko-egotheismitis," derived from *neuron*—nerve, *politikos*—political, *egotheism*—self-worship, *itis*—inflammation, or a species of inflammation of certain nerve centres of the brain which control our sense of politics and self-worship. The disease is one that calls for gentle and kindly treatment; the patient must be persuaded out of his neurotic condition by showing him that his bogeys are merely hallucinations. How can we do this? I am afraid the answer to this question is not an easy one; but the question must be answered sooner or later, otherwise it is certain that if the various municipal authorities owning supply undertakings cannot find a way of mutual co-operation between themselves, and between themselves and the power companies, somebody will step in and answer it for them.

I do not propose to attempt to solve the political side of the trouble, but merely to call attention to it and express a pious opinion that, if this element could be got rid of, the way would be made easy for complete co-operation among all parties concerned. Frank and open dealing one with another will also tend to improve matters. At the present moment the smaller undertakings are under the impression that the larger undertakings want to swallow them up. This is a fallacy, as the small undertakings cannot be swallowed up unless they are consenting parties, and, again, it is not to the advantage of a power company to take over the distribution of current. They are wholesale dealers and do not want to retail.

The engineers and managers of some of the smaller undertakings seem also to think that there is danger ahead. They fear they will suffer loss of prestige and that their status will be lowered. With this fixed idea in their heads it is hardly possible—indeed, it is contrary to human nature—to expect them to give unbiased advice to their Councils.

Surely these officials have nothing to fear. If the manufacture of electricity is taken out of their hands, experts will still be required in other directions. Just because the boiler house disappears do they think that their position will suffer? I firmly believe that, on the other hand, their position will be improved.

Bulk supplies must eventually reduce costs, and with a cheaper supply the sale of energy and the income derived will increase, the engineer undoubtedly benefiting by the general improvement. The salary paid to a manager of a retail business depends principally on the turn-over.

The distrust and suspicion I have referred to are not confined solely to those operating electricity undertakings. Many large firms have the same feelings, but let me at once say that our best friends—our customers—who receive the power supply from the power company with which I am associated, are not amongst the doubters. Once we get them connected to our circuits all troubles disappear and we become a happy family. It is a fact that during the period of operation my company lost only one customer, and I am glad to say that he will soon be regained.

Large bulk supplies are given by the Clyde Valley Company to municipally-owned as well as to company-owned undertakings, and the relations between all parties are of the best. It is worthy of note that one of these company undertakings is, with the exceptions of Glasgow Corporation, Greenock Corporation, and the Clyde Valley Company, the largest undertaking in the West of Scotland. The company referred to is in no way allied to the Clyde Valley Company, yet it paid the supply company to shut down their generating plant and take a bulk supply. I will not press the moral.

NORTH-WESTERN CENTRE: CHAIRMAN'S ADDRESS

By W. Walker, Member.

(Abstract *of Address delivered at* Manchester, *15th November*, 1921.)

Coal Reserve.

The outstanding incident of the past year was the coal strike, on account of the direct and indirect effect which it had on every branch of the electricity supply industry.

At the start of the strike, conditions similar to those in former struggles were found to exist in the industry: a few undertakings had ample coal in reserve, many had a little, and others none at all. Some at least of the last mentioned were without any reserves on the occasion of every previous dislocation of supplies, and it is undoubtedly the result of a deliberate decision not to expend money for this purpose, but rather to rely on some Government Department coming to their aid by diverting to them coal belonging to other undertakings.

I desire to bring home to those responsible for this policy the exasperation which it excites. The provision of an ample reserve of fuel is an insurance. It is somewhat costly, but a good manager makes the provision and then reaps his reward from being able to keep the industries of his area fully at work instead of shutting them down and increasing the general loss and dislocation. Imagine, then, the feelings of such a chief engineer on being informed during the first week of a coal strike that all his carefully-laid plans have been entirely dislocated, by reason of his supplies being diverted to another undertaking which he knows has never made an attempt to grapple with the problem and has boasted of saving money by such a policy. These diversions have been made without the real conditions being investigated, often solely because the stock returns showed that one undertaking had some thousands of tons while the other had little or none. The actual position of the dump, or the possibility of being able to get the amount required per day into the boiler-house bunkers, was not considered.

I believe that every undertaking ought to do all that it can to assist another which is in trouble due to causes beyond the control of the management, but I am unwilling to help those who have never made an attempt to help themselves.

The insurance effected by providing ample reserves of coal is fairly expensive. The cost comprises three factors—deterioration, double handling, and the capital charges on the money which is locked up. For normal deterioration from weather there does not appear to be for most undertakings any radical remedy such as under-water storage, nor is the loss from this cause very serious, being 1·2 per cent for the first year and 2·1 per cent for two years. The chief danger is spontaneous combustion, and against this it is necessary to take precautions. Coal from 2 inches in size upwards allows sufficient air to circulate throughout the whole of the dump to prevent spontaneous combustion, and very fine coal, by preventing all circulation of air, produces the same result. When the coal consists of pieces between these limits, fires are likely to occur.

It must be remembered that the heating is the result of action at the faces of the pieces of coal which comprise the heap. If each ton were a cube, then each face would be about 2 ft. 8 in. and the total area 47 square feet. There is an enormous increase of this area of potential danger as the coal is more and more broken up. The surface area of a ton of coal broken to pass a 16 mesh is 1 acre. One investigator * states that "the question of heat generated at the surface of a piece of coal depends largely upon the temperature of the piece, hence the necessity of putting the coal into stock when at a low temperature." The rate of chemical reaction doubles for every 10 degrees F. rise in the temperature. Much importance has been attached to the height to which the coal is heaped, because of the supposed effect of pressure at the base, but it is fairly obvious that height alone would not give the result with which it is credited, for if we could build a thin wall of coal to a height of hundreds of feet, we know that combustion would not take place at the base because there would be an ample circulation of air.

The next item of cost, that of capital charges, cannot be evaded, nor is it subject to any influence exercisable by the engineer.

The heaviest item, and the one which in many cases can be reduced, is that of handling.

Coal Handling.

At the present time many methods, often very crude, of handling coal are in use, ranging from manual labour with spade and barrow to the grab. A revolution is, however, taking place. For many years the pneumatic principle has been successfully applied to grain-handling, and to-day large installations are working well and economically in many parts of the world, and it is significant that for the latest and largest projects it is stipulated that pneumatic plant only will be considered.

The system itself was first developed by the late Mr. F. E. Duckham for the discharging of grain cargoes at Millwall Docks, but it has not worked its way into favour rapidly. Nearly a generation has passed since the first successful plants were constructed in London, and, although the system has been firmly established on the Continent for some years, in this country it has needed the impetus given by war conditions to the solution of handling problems to bring the pneumatic

* C. P. Hood, Chief Mechanical Engineer, U.S. Bureau of Mines.

system to supremacy even in its first field, that of discharging grain cargoes.

Some of the engineers concerned in the development of the method have long advocated its adoption in certain classes of cases for the handling of industrial coal, but it is only very recently that a few enterprising concerns have given them the opportunity of putting their suggestions into practice. A parallel development appears to have occurred in Germany during the war where, however, only small plants have been installed. Some work in the same field has been done in America.

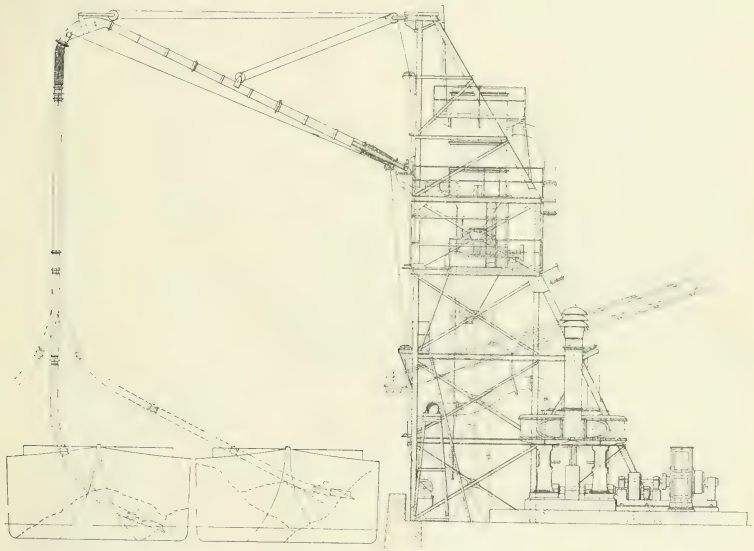

FIG. 1.—Cross-section of the pneumatic coal-discharging plant for the City of London Electric Power and Lighting Company, Ltd.; capacity, 120 tons per hour.

I believe, however, that the plant (see Fig. 1) which was recently put to work by a firm of Manchester engineers at the Bankside station of the City of London Electric Power and Lighting Co., Ltd., with a total capacity of 120 tons per hour, is by far the largest in the world.

The drawback which has hampered the progress of the pneumatic plant is, of course, its heavy consumption of power. Great improvement in this respect has been effected during the last 10 or 12 years, and it has been suggested recently that still greater economy is to be looked for in the future. This prediction was, however, based on laboratory experiments, and although other investigators have themselves found no difficulty in obtaining striking results under similar conditions, I have grave doubts whether these will be attained under commercial conditions for a long time to come, except perhaps in a few exceptionally favourable cases.

Considerations of first cost, simplicity, reliability and practicability, impose a limit on the degree of refinement which can be recommended. Further, it should be noted that the tendency of the cost of labour, both in wages and in supervision, to increase relatively to the cost of power, tends to diminish the importance of this factor in all calculations relative to mechanical handling systems. In any case I hope that the pneumatic method will be employed for the solution of only that part of a handling problem to which it is particularly adapted. It should never, for instance, be adopted as a substitute for a band conveyor, the efficiency and simplicity of which within its own range of usefulness are unsurpassed.

I have been brought into intimate contact with work which is being done in the application of the pneumatic method to the handling of coal and I have

very great faith in its future. I make no apology therefore for referring briefly to what appears to me to be one of the most interesting and promising of the matters which have come into prominence during recent months.

The pneumatic system is commonly spoken of as suction system, on account of its most useful form, and there is a tendency to think of the coal as being driven through the pipes by the pressure of the atmosphere, as water is propelled by pump suction. Questions are asked about the limit of height to which the coal may be lifted, as though something in the nature of a coal barometer were possible. Needless to say, this is not the case. The coal is carried along by the impulse and friction of a stream of air moving at a speed materially greater than the speed of the coal, in the manner which is already familiar to many power station engineers who have adopted pneumatic ash-handling plants. It is interesting to note, in passing, that whereas pneumatic coal-handling is historically a development of grain-handling, and all the plants installed here and in Germany have partaken of the nature of grain-handling plants, pneumatic ash-handling has been evolved quite independently and on somewhat different lines. It may fall to power station engineers, having experience of both types, to improve both of them by a process analogous to cross-breeding.

In a suction plant the coal is drawn into a settling chamber or receiver and this is the most widely useful arrangement, but under certain circumstances—when, for example, the coal is to be conveyed from one or two fixed spots and distributed over an area—it may be fed into a pressure pipe and blown to its destination. If, however, it is discharged in the open in this way, the resulting dust is apt to be inconvenient. In some cases a combination of both methods may provide a solution of a problem otherwise difficult. The coal is removed from the receiver by means of a sealing mechanism, which acts on the pressure system of the air stream as a lock does on the pressure system of a river. Indeed, Duckham's name for his mechanism was "air-lock."

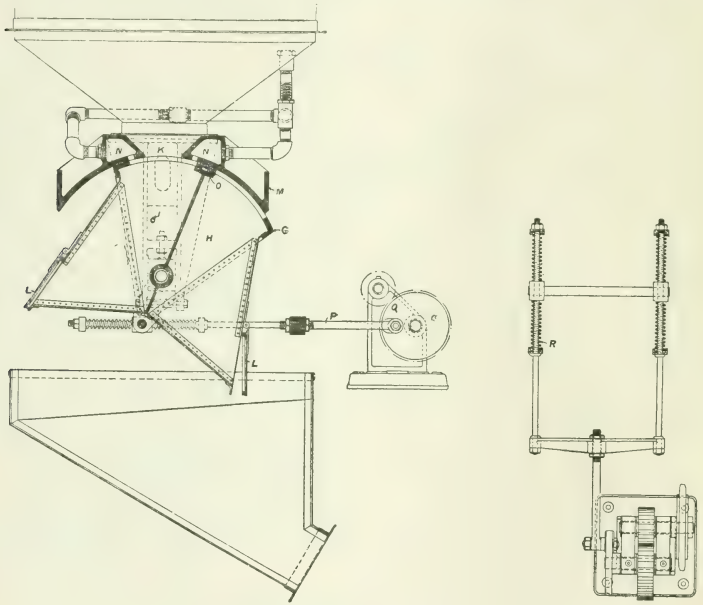

FIG. 2.—Discharging tipper seal.

The following is a description of the discharging mechanism or tipper seal (see Fig. 2). The rocking

member (G) contains two pockets (H, J) which are alternately brought into communication with the outlet (K) of the receiver. While either pocket is thus engaged, and therefore under vacuum, its hinged discharge door (L) is held closed by the pressure of the atmosphere. Simultaneously, the other pocket has been swung far enough over to admit air through the feed opening, and has permitted the hinged door to open and discharge its contents. The frame of the tipping box, including the circular rubbing face, is of cast-iron, and is pivoted in adjustable bearings, the bearings being supported by brackets carried from the upper or seat casting (M) in which ports (N) are arranged for exhausting the air from the pockets before coal is admitted to them. The object of the latter arrangement is to prevent the inrush of air carrying the coal over and into the dust collector. The air-tight joint between the tipping box and the upper casting is made by two means. There is a steel packing strip (O) held in the cross bar between the two pockets against the face of the upper casting by bow springs, and at the sides and ends of the rubbing face of the tumbling box leather strips are provided. The hinged discharge doors are also rubber faced to make an air-tight joint.

The vacuum pump, dust separator and connecting pipes complete the list of the essential parts of a suction plant.

The parts of a blowing plant are of course somewhat similar, but differently arranged. The vacuum pump becomes a compressor, there is no receiver, but there may be an expansion chamber to steady the air flow. The air-lock or seal passes the material into the pressure pipe instead of extracting it from the vacuum chamber, and it is not always possible to include a dust separator.

The class and condition of the coal affect to some degree the efficiency of the plant and the rate at which it will handle the material. There is also the question of the size of the coal, which must of necessity be small; it is usual to specify 2 inches as the maximum size, but if the pipe be not too small, and the proportion of small stuff be large, lumps of 4 inches to 6 inches will pass through without difficulty. On the other hand, fine dusty stuff may cause trouble if it is very wet. Broadly speaking, a pneumatic plant handles most satisfactorily free-running or "lively" materials.

A brief description of the plant now being installed at the Brimsdown station of the North Metropolitan Electric Power Supply Co. will illustrate some of the possibilities of the system, particularly with reference to the question of coal storage.

Coal arrives at this station both by rail and by water. There is a barge dock some 40 ft. or 50 ft. from the end of the boiler house, and storage dumps are arranged round it. The railway siding is on the far side of the power station, nearly 200 ft. from the boiler house. The new coal-handling plant is arranged as shown in Fig. 3.

There is a light steel structure at the end of the boiler house nearest to the barge dock. At the top of this is the receiver and tipper delivering the coal, through an automatic scale, to a belt conveyor running over the top of the bunkers, with a travelling tripper. The dust separator or filter is also here, and its contents can be discharged from time to time on to the belt conveyor. The vacuum pump is placed in a small building at the foot of the tower. A swinging pipe, pivoted on the front of the tower and supported by a steel jib, commands a barge lying in the dock. It has two detachable flexible branches for working in the barge. A wagon tippler is provided on the railway siding, and a second pipe runs from the receiver across the end of the power station over the office roof to the tippler pit. A third pipe, suitably branched and provided with connections at intervals throughout its length, commands the storage dumps and terminates at a point on the arc described by the swinging pipe near the head of the dock, so that, when the flexible branches of the swinging pipe are removed, the latter may be connected to the store pipe and coal transported from the store through the weighing machine to the bunkers.

Experience in grain-handling work has revealed an astonishing variety of possibilities in the design of such plant to meet special conditions. The first plants were built on floating pontoons. All kinds of travelling plants have been built, including a number fixed on ordinary coal trucks and restricted by the ordinary railway gauge. The utility of some such apparatus in dealing with scattered storage dumps will be obvious. I am, indeed, confident that time and experience, whilst doubtless revealing limitations both technical and economic, must also indicate a continually widening scope for the application of a handling system so flexible and adaptable by its very nature.

Oil Fuel.

Another aid to continuous running during a period of coal shortage is the use of oil as fuel. The recent strike caused a great addition to the number of oil-fired boilers, but apparently the system will be retained on only a few now that coal is again available. It is very difficult to reconcile the notes and figures given by some of those who have made the experiment, but we may take 14·5 lb. of water evaporated per pound of oil as being a fair figure, and as a general proposition we may say that to justify a change from coal to oil the selling price of oil must be a little less than double the selling price of coal.

The chief engineer of an undertaking having the largest oil installation in the country has written to me that: "I am sorry that our results have not been sufficiently conclusive to enable me to quote any definite and satisfactory figures regarding the use of oil firing. . . . We have endeavoured to utilize the experience of other users, and also the expert knowledge of all makers of fuel burners, but have had the greatest difficulty in securing consistent results. . . . Sometimes we get a good result equal to a boiler efficiency of 85 per cent, and a little more than 15 lb. of water evaporated by 1 lb. of fuel oil, but more frequently we get inferior results, for which we cannot always obtain a reasonable explanation. The whole thing is a tricky business, but will undoubtedly repay careful testing work."

There is a great diversity of opinion in regard to burners. It is interesting to note that a temperature 300 degrees F. lower is obtained if steam is used instead

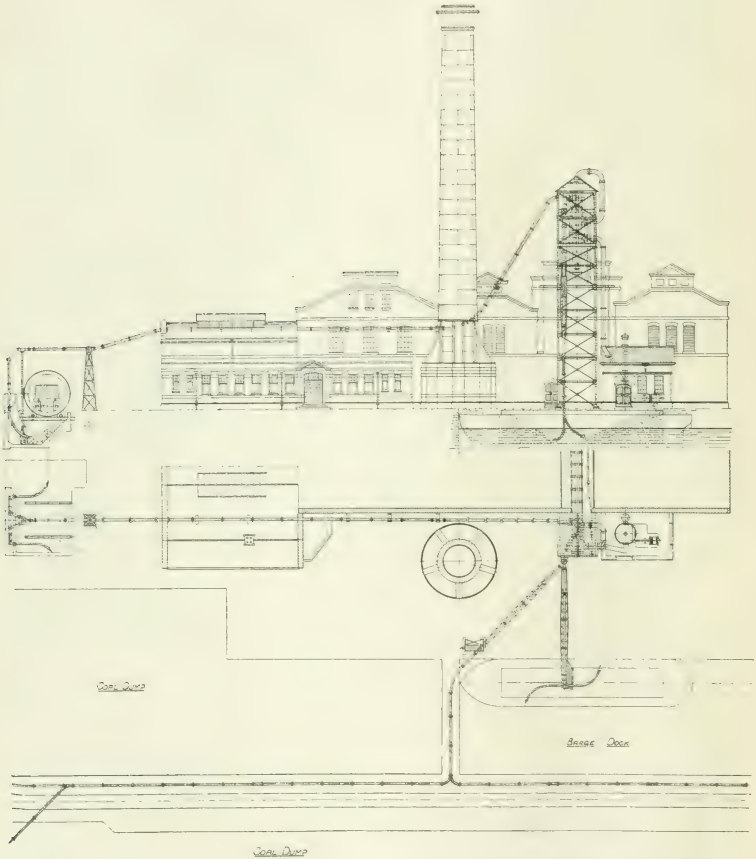

Fig. 3.—Pneumatic coal-handling plant being installed for the North Metropolitan Electric Power Supply Company. Elevation and plan showing the lay-out of pneumatic plant for discharging coal from barges and conveying coal from reserve dumps and from tippler hopper on railway siding.

of air for atomizing. The same quantity of air is required—the steam being so much loading. This does not necessarily mean that it may not be more economical to use the steam direct for atomizing instead of for compressing.

Electricity and Gas Supply.

The use of town's gas for steam-raising has not made any progress, nor does it appear likely that it will do so until a gas works has been designed and erected with that idea in view. It may be found necessary to allocate a number of the retorts and holders for the production and storage of gas of a lower calorific value and degree of cleanliness (a sort of by-product) for the special purpose of supplying the neighbouring electric power station. It would be necessary to examine thoroughly what the effect on both works would be of such a combination if developed to its utmost. The problem would have to be approached with open mind and with all jealousies eliminated. Such an opportunity may occur when the second part of the new Manchester electricity supply station is required, as by that time the Gas Department will be ready to develop their plans for the new gas works at Partington, the site of which is conveniently near the electricity station. If the advantages of a single coal-purchasing department, a saving in the cost of handling fuel, the production of valuable by-products, a reduced area of land, less supervision and labour, and all other factors are dispassionately considered, it ought to be possible to arrive at definite conclusions on this very important matter.

It is not so simple a problem as is sometimes assumed, as I know from experience gained some 10 years ago when we examined the possibilities of taking a supply of gas from the Bradford-road works in Manchester for either boiler-firing or large gas-engines. I was then convinced that the only chance of success would be to take advantage of the construction of new electricity and gas works so combined as to secure the elimination from each of everything which could be done more economically at the other.

I do not suggest, of course, that the combination shall be for the supply and use of gaseous fuel only, but that it shall be for gas, coke, coke-breeze, and also coal which has been subjected to a process of low-temperature carbonization.

Pulverized Coal.

This system has been adopted in a far larger proportion of cases in the United States than in this country, yet it is difficult to account for this except by concluding that the American engineers have followed one another's lead as results have become known. The first successful, commercial, pulverized coal installation of some 20 000 square feet was made four years ago. During the next $2\frac{1}{2}$ years an additional 200 000 square feet only was put in operation, but during the last $1\frac{1}{2}$ years 700 000 square feet of heating surface has been installed for burning pulverized coal.

I can understand the hesitation to install the system, because it introduces an entirely new set of conditions into a station and increases the number of danger points. On the one hand, it adds to the varieties and qualities of coal which can be used, it gives more perfect combustion, greatly improves the control over the steam-raising plant, requires only sufficient excess air to keep the temperature within the limits which the furnace lining will stand, it does away with the problem of the formation, removal and disposal of clinker, and chimney losses are reduced. Whereas, on the other hand, additional and comparatively expensive plant is required for pulverizing, drying, conveying and blowing the coal.

In itself, it is a very marked advance on any other method of burning coal. Imagine one of these pulverized particles, 80 per cent of which will pass through a 200 mesh, being blown by means of air into the already incandescent combustion chamber, and think how much greater are its chances of becoming CO_2 instead of CO. During tests in the United States it has been found to be easy to maintain the CO_2 contents of the flue gases at 17 per cent, but of course this meant a temperature too high for the furnace linings, and excess air had to be admitted to get the flame temperature down to 3 000° F. and the brickwork temperature to 2 500° F.

The increased adoption of the system in this country appears to depend largely on the essential preparatory plant being made available at prices much below those which have so far ruled. If this can be done there will be a great expansion, and there does not appear to be anything in the plant itself to warrant some of the high prices which have been asked, but, of course, costly experimental and development work has had to be done.

Industrial Conditions.

The labour conditions within the industry are to-day more settled than they have ever been before. As the outcome of long and patient negotiations the wages and conditions of service for every man in every undertaking in the country were made the subject of an agreement. The duties of each man were defined and the former state of chaos was ended. Owing to the recent fall in the cost of living it became necessary for adjustments to be made, and I am pleased to say that at a meeting of the National Joint Council in London 10 days ago a resolution for adopting the report of the Negotiating Sub-Committee, by which the wages of the manual workers in the whole industry are automatically regulated for a long period ahead, was passed unanimously.

The National and District Boards have made provision for the technical staff. I have seen the two organizations grow up from their birth. They met difficulties, but to-day they have justified themselves, and I have been told by members of the Ministry of Labour that the completeness of the organizations, the results obtained and, more than all, the spirit which prevails, are better than those in any other industry.

The Working of the 1919 Electricity Act.

We have now had an opportunity of seeing the procedure and methods of the Electricity Commissioners,

and of ascertaining to some extent what effect they may have on the industry. The greatest and almost universal note of adverse criticism is directed against the complicated and expensive procedure. Each succeeding Inquiry has become more prolonged and more costly and more and more like the proceedings of a parliamentary committee. As one who, from the first, advocated the appointment of Commissioners with the widest possible powers, and in whom, now that they are appointed, I have the most implicit confidence, I regret that they have been persuaded to put this barrier of costly and complicated legal procedure between themselves and the management of the supply undertakings.

Legislation of the Last Session.

It is regrettable that whilst legislators keep informing us that it is the settled intention of the Government to introduce and pass the Electricity Supply Bill No. 2, they continue to follow the line of least resistance and to postpone or withdraw it in accordance with what they consider to be the political requirements of the moment rather than the industrial necessities of the future. We have the right to know the conditions under which we shall have to operate during the next few years, and nothing is more disturbing than uncertainty. Without discussing particular clauses, it is generally agreed that a Bill ought to be passed without further delay.

The past parliamentary session has not produced much legislation affecting our industry, the decrease being accounted for to some extent by the powers given to the Electricity Commissioners to grant Special Orders which take the place of the Provisional Orders formerly granted by Parliament.

Of the Safeguarding of Industries Act I should like to say much, but it is too controversial a subject for a Chairman's Address.

Of the Telegraph Act I need merely say that it sanctioned the expenditure of a considerable sum for the extension of the telephone system.

In this area the 1919 Electricity Act brought a great amount of work to some of our power-station engineers, and the result of their labours is a credit to them. They have grasped the fundamental difference which was made in the situation by the withdrawal of the financial clauses of the 1919 Act, followed as it was by the failure to carry them in the 1920 Bill. The most important part of the Act, after that which appointed the Commissioners, was to provide for the creation of Joint Electricity Authorities in each of the electricity areas. The powers, functions and constitution of these Authorities were laid down. They were intended to be all-powerful within their area, and to possess and control all generating stations and main transmission lines. The fatal flaw, however, was that they were left without financial powers and, although these have been promised again and again, they have not materialized.

There is at the moment no Joint Electricity Authority in active being, though schemes for setting them up in several areas have been submitted to the Commissioners and approved by them. The Committee appointed to prepare a scheme for this area decided that a Joint Electricity Authority without financial powers would be of little use, and they have therefore recommended the formation of an Advisory Board and formulated its duties, outlined its organization, and drafted its constitution. Every constituent undertaking, municipal or company, is asked to bring a standard resolution before its supreme controlling body by which it agrees to take part in the formation of the Board and act under the advice of such Board. The greatest difference between a Joint Electricity Authority and an Advisory Board is that the first has powers of compulsion, whereas the latter can only advise; but it is certain that the Commissioners will not readily grant powers to carry out developments or extensions against the recommendations of the Advisory Board. The technical scheme is thoroughly good, especially so, because it resists the temptation to recommend the shutting down of existing power stations merely to make room for superstations; instead, it suggests steady progress towards the realization of the goal, of which every step has been carefully considered and all the conditions have been fully examined and explained.

Present Conditions.

In conclusion, I propose to say a few words on the present. We are going through a very trying period; the great industrial depression has reacted on us and all supply undertakings are being severely tested. In the past years our Reports have been of regular and rapid progress. We have been able to estimate the future requirements from past experience, but to-day there is retrogression; load has gone off, no one being able to say how soon it will return, and, as it is impossible to reduce expenditure as quickly and in the same ratio, our financial resources are being strained. If we are compelled to increase our prices for energy, the effect will be to extend the period of industrial depression by increasing the costs of the manufacturer, whose sales will be re-established only when the selling price of his productions has reached what the buyer can and will pay.

For the purposes of power and lighting, electricity is firmly established in this area and need fear no rival. As regards private lighting, however, we do not deserve our success. With the most flexible system it is possible to imagine, with fittings at our command for every conceivable position and purpose we can find in our principal streets numerous examples of high candle-power lamps suspended on flexible cable and close up to the windows, at the height of the average person in the street, the filaments unscreened so that the source of light is almost directly in contact with the eyes of the person wishing to examine the contents of the window. Every law of illumination is broken, and all without a shadow of excuse on grounds either of cost or of necessity. For one good example of lighting there are 20 bad ones, and those who sell current should be given powers to prevent its misuse.

I have been wondering what may possibly be done in the dark recesses of an installation if misuse such as I have described can be committed openly. It is no use saying that the shop-keeper or the householder is

at fault. I have ample evidence to the contrary. The majority have accepted the schemes put before them by the contractors, and it is for the latter to make use of proper appliances, which are readily obtainable, instead of acting as though nothing existed but a length of flexible cable, a lampholder, and a lamp. The few good examples of shop and shop-window lighting here, and the many in some other towns, show how easily it can be done if the will and the interest exist.

Finally, a personal note. I feel deeply the great honour you have done me by making me the Chairman of this important Territorial Centre. It is many years since I joined the Institution. During the intervening period I have been engaged in applying to commercial use the appliances which are the direct outcome of the discussions of those days. I place such common sense and energy as I possess at the service of the Centre, but in addition I shall require your loyal assistance and support, then together we may be able to accomplish something for our Centre, for the Institution, and for the great profession to which we are so proud to belong.

NORTH MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By W. E. Burnand, Member.

(Abstract *of Address delivered at* Leeds, *15th November*, 1921.)

In the rapidly-changing world of to-day I think it will be readily conceded that the outstanding features on the social side are the labour question, running side by side with the question of economics, and, on the scientific side, the relativity theory, running parallel with the electron theory.

I do not know that there is any connection between the two, but they seem to have become prominent about the same time after nearly the same period of incubation; both represent a sort of twin product, and both are almost revolutionary in character and world-wide in their effects.

I have put what is referred to as the "labour question" first, as I think it is the first in importance and, unless solved in a workable manner, it will not only eclipse but practically extinguish most of our other interests.

It is often said that labour unrest is the result of the war, but I think that, apart from the increased volume of unemployment, this is only to a small extent correct. It was very prevalent in the early part of 1914, and the effect of the war was first to check this, then to inflame it further, leaving all ready for a full eruption when the "peaceful days of the war" had passed.

As with all human affairs, we do not get a clearly traceable line connecting cause and effect, but the effect is the resultant of innumerable causes, some acting one way and some another, many cancelling out but leaving effects we see and feel around us to-day.

Speaking of our own country, it is not very cheering to remember that, although we are professedly Christian, the worst of our labour troubles would be impossible if we were really so. Is it possible to reconcile with the first principle of Christianity—to "do unto others as you would they should do unto you"—most of the causes of trouble at the present time? I do not think the miner, for instance, likes to get short weight when he buys something, but is he not giving short weight when he produces three tons of coal when he could quite easily produce four, and similarly the bricklayer who lays half the number of bricks he knows he can lay?

I would mention here that I do not think the whole blame for this state of things attaches entirely to the workmen; an equal share must be laid to the antecedent conditions which caused the men to adopt these tactics. Again, I do not pick out these two trades because I think the workmen engaged in them are any worse or any better than men in any other trade—probably they will compare quite well with any other body of men—but I mention them, first, because they are universally known, secondly because the results of their short-weight-giving propensities fall most hardly on working men, and thirdly because it is significant that they belong to the most thoroughly organized trade unions. I believe these trade unions have done much good work in improving the lot of the unskilled and semi-skilled worker, and that much good work remains for them to do, but it seems a great pity that through false and unchristian ideas all the good they have done appears more than likely to be undone.

Few people will deny that without employment the lot of the worker must be worse than if there were reasonably full employment; yet we know quite well that the high cost of coal is keeping tens of

thousands of men out of employment. In the building trades also, costs have risen, due more than anything else to trade-union rules, to a figure that runs away with so much of a workman's wage for rent that he has, in some cases, to go short of the necessities of life, has to put up with inferior housing accommodation, or, in other cases, has to do without a house altogether. From the owner's standpoint the rent simply does not pay on the cost of the property a return equal to that which he can get elsewhere with less trouble.

In spite of the house shortage that will take many years to make up, it is notorious that building unions which are short-handed will not admit men having the strongest possible claims on their consideration. To admit these men would provide them with employment, which again would enable men who are on short time in other unions connected with the building trades and who are now waiting on the short-handed trades, to go on full time, and would enable more of those who are now homeless to get a home.

In spite of this, the men willing to work are not allowed to do so on account of trade-union rules. It is absurd to say that these unions as now worked are for the benefit of the worker; it is simply their own little section that is looked after in this short-sighted fashion, and the manner of their working is to create by intimidation, in their own particular class of labour, a "corner" and exploit it by keeping supplies short and dear. Nominally this is directed against capital, but actually it acts chiefly against the workmen themselves, who in their turn are in some other union acting in the same way. We thus get the "vicious circle" which hits the capitalist occasionally but the workman every time, and, certainly, for every shilling they take out of capital, these methods take at least 10 shillings in value from the workers.

I have dealt with this aspect of the labour problem not because I hold any brief for capital, but because I believe that it is responsible for untold misery among the working-classes to-day, and that, if the trade unions will direct some of their energies in a constructive direction, there is employment waiting for them in reconstructing and improving their own country so as to tide over the period—which is not likely to be short—that will elapse before our foreign trade gets into its stride again.

I know my labour friends will say that this is a very one-sided statement of the case, and that the capitalist does in his way all that labour does, i.e. that he tries, when the opportunity arises, to create a corner in supplies, and thereby extorts all he can out of the rest of mankind, and that he has exploited labour in the past and will do so again if he can in the future, and will think this is the reason that trade-union rules have grown as they have done. Whilst not conceding the whole, I am bound to agree with much that labour has put forth in this respect, but I put the unions' imitation and improvements on these practices first as the cause of the troubles of the working class, because, though both are equally selfish, the capitalist does less harm to the State and to the working man himself. If he creates a corner in any essential commodity he can be sent to gaol. If he "sweats" labour and makes a big profit thereby, the bulk of these profits eventually goes to labour. The man who is keen on making money is seldom keen on spending it, therefore he is not likely to spend a great deal on his personal wants. The bulk of the money so spent inevitably goes to labour. Also, his income is heavily taxed and he makes a substantial contribution to the cost of carrying on the State's affairs. On what is left he has only a life interest, since obviously he cannot take it with him when he dies. The State then comes in again for a substantial proportion, and, as the working class forms the larger proportion of the State, it secures corresponding benefit. Again, the goods produced or distributed in greater quantity by the driving power of the "sweater" must benefit the people who get them.

If he is a builder, for instance, who by miraculous powers hustles his men to such purpose that they build two houses in the time it would otherwise take them to build one, and thereby quadruples his profit, the immediate effect is that the men immediately under him are unfairly treated in that they have to do double the amount of work they would otherwise have to do for the money. If the workmen in question said that this was equivalent to thieving I would not contradict them. In that respect this is exactly equivalent to the action of the worker who gives short weight in his work. The results beyond the immediate circle are, however, far less pernicious, since someone gets a house who otherwise would not do so; the demand for building materials is increased, thus improving employment elsewhere (and even the most ardent trade unionist will agree that a demand for his goods tends to keep the rate of wage up as well as to decrease short time); and the State gets a very substantial proportion of the profit made. Thus the State as a whole benefits by almost anything that increases production, although the maximum benefit to the State results only where there is a square deal with the workman, whilst restriction of output injures all but a few selfish individuals in the first instance, and eventually even these individuals themselves.

Modern trade-union policy thus injures the workers by:

(1) Restricting output, which (*a*) increases cost due not only to the extra cost of wages but to increasing scarcity, and thus raises still further the prices that have to be paid; and (*b*) decreases the demand for goods in trades other than the one restricting output, and thus leads to short time, unemployment, and low wages.

(2) The policy of injuring and retarding the developments of industry. It should surely be obvious that if a workman is to get a good wage the first essential is for his industry to be prosperous. If there is plenty of money coming into the business there is a chance of getting something out of it, but if it can barely pay its way the chances of benefit to the workman are small, and if their wages are increased it simply leads to unemployment later.

Whilst I have occasionally heard a sort of lip service to the idea of helping industry along, I personally have never come across an instance where a union has

done anything to develop and help industry. Whatever has been said, what has actually been done, has been obstructive.

The idea, of course, is to hit the capitalist, and in this I think they are successful, but labour suffers most acutely since these actions increase the costs of necessities to those of luxuries and decrease the wages with which the workman has to buy them.

My sympathies are with labour, but I think the latter might get a more enlightened policy and dismiss the incompetents who style themselves leaders and preach a policy of greed and obstruction which is really disguised industrial suicide. I would ask working men to observe the way in which these leaders do their work and then ask themselves if they will, or can, work for them any better. I believe workmen are already beginning to think on these lines and will eventually act upon them. They may then choose leaders with brains instead of a parrot-like repetition of invective, and we may see labour hiring capital instead of capital hiring labour, and labour choosing and paying its foremen and managers instead of the capitalist doing so.

No doubt some will say that if we are to continue to have capitalists, managers, and foremen, this comes to the same thing as at present, but actually it would work out in a very different manner. The managers and foremen being appointed and paid by the workers would naturally study things from the workers' point of view rather than from that of making the maximum return on capital, i.e. they would not try to benefit capital at the expense of labour, but would take a broader view of the whole. Also, since the profit beyond a modest amount paid for the use of capital would go to the workers, and the control would be in their hands, the incentive to efficient production would be so direct that real and substantial profits would be made and the workers themselves would then gradually become the chief capitalists. All this, of course, will not come about in 12 months, but I think there will be a strong movement that way within 12 years, which, in view of the present-day estimates of the age of the earth, is not such a very long period.

I wish to suggest not that some such system will supersede all present forms of industrial organization, but that a start will be made in a few years and will gradually spread, especially among industries employing a large number of men. As the workmen gain experience the increased efficiency resulting would render it impossible for the older systems to compete in some industries and would, as it were, "set the pace" for others.

It does not follow that capital would suffer more than under present-day conditions, as I think that in industry capital as a whole is getting no profit at all and is being lost at a much greater rate than it is being made. Even on a pre-war basis the rate of return in limited liability companies as a whole was something under 5 per cent and, though it may be debatable whether capital ought to get interest at all, it is quite certain that to attempt to get capital without paying interest would cost more than to pay what is recognized as a fair rate of interest.

It has been demonstrated that labour left to itself produces so little that a large proportion of the inhabitants must die of starvation in a densely populated country.

In the meantime, this country is not paying its way and the majority of other countries are in worse straits. It is a sorry time for the unemployed workers, and the time of their lives for the unemployables, agitators and shirkers. Strikes have had their day, even if we have not yet finished with them, as the harm done by them is gradually being realized by the masses. Whilst I think that strikes have done untold harm, I am far from putting all the blame on the strikers. What I mean is that the greater part of what the strikers have got ought, as a matter of justice, to have been granted without even the threat of a strike. Plenty of just demands have been shelved for years, and then granted almost directly when a strike has taken place.

This being so, is it a cause for wonder that strikes have been so frequent and that, having been so successful compared with other means, they should spread and that the striking bodies should over-reach themselves? It seems to me that the employers must take at least an equal share of the blame for this state of affairs and its deplorable consequences.

If the demands were just (and many of them were) they should have been granted without a strike threat being necessary. If unjust, they should not be granted at all.

It is difficult to conceive any more direct encouragement to strikes and eventual fixing of rates of remuneration, and to government by intimidation instead of merit or value, than the opposite policy that has been adopted in so many instances, and we are now reaping some of the harvest.

In a country like ours, which is not self-supporting in the matter of food and many raw materials, and is dependent on supplying its products to other countries for much of its prosperity, the condition of these other countries is of vital concern to us, and he is indeed an optimist who can believe in any great revival in these at an early date. It is often pointed out that Germany is going ahead industrially at a great pace, and there is no doubt that many of their factories are on full time, while ours are almost at a standstill, and that their exports have gone up at a far greater rate than ours, due, of course, mainly to the favourable rates of exchange, although the naturally industrious habits of the people are not a negligible factor.

Whilst this industrial activity is often contrasted with our comparative stagnation, and the inference is drawn of their comparative prosperity, I do not think this takes into account all the facts.

When Germany sells something to a country whose currency stands high, say to Great Britain, she gets in exchange a sum representing perhaps a great many marks but not many sovereigns, and, eventually, materials that these will buy. For example, suppose Germany sells something to us for £1 with a normal value of £2. The country as a whole obviously loses £1 on the transaction, but the exporter can exchange the £1 received into an enormous number of marks, representing at present about £40 (German money). This

figure is rapidly changing, but whether it is £5 or £100 the effect of these two actions is to transfer the wealth of the country partly to the exporting section of the country and partly to foreign countries. Thus, the country as a whole continually gets poorer if a big export trade is carried on. The effect of an adverse rate of exchange is similar to that of a bounty on exports, which may conceivably be a good thing within limits and give an impetus to exports, but when this bounty increases to 50, 100 or more per cent, the country pays too dearly for the trade thus obtained. This provides still another factor depressing the international credit of the country and reacts in turn on the domestic value of its currency, eventually raising prices to a prohibitive extent.

This rough review, of course, leaves out all sorts of intermediate factors, and the values cited are elastic to a great degree; but broadly this is what is happening, and to go into details would take up far too much time, without making the matter proportionately clear.

It is evident that nothing has so far taken the place of the gold standard as a medium of international exchange, and that, in the absence of such a standard, currencies are stable only within small limits. When these limits are exceeded, currencies of low international value tend to become smaller in value and those of high value larger, until a breakdown ensues and currencies cease to be of value as a medium of international business. I believe that a Commission is trying to devise something equivalent to international currency, but the work is very difficult and I should not be surprised to find a system of trade by barter, with possibly a limited application of the gold standard, well under way before a really effective medium of international exchange is evolved and utilized. In any case, international trade is crippled for years to come, and in the meantime unemployment remains with us. For this reason I commenced my Address with this subject.

There is no one sovereign remedy for this state of affairs, but all possible ways should be utilized. One of the biggest factors appears to be almost the least utilized—I allude to the factor known as self-help. This implies an active personal effort on the part of the worker to look out for and make fresh avenues of employment. Here, again, trade-union policy is purely obstructive. On the employer's part it implies looking out for and making fresh channels of business, developing inventions, improving plant and the like.

Far too much stress is laid on Government action. It is said that the unemployment problem is too big for local action, so it must be tackled by an already overloaded Government. Personally, I think it is by innumerable local and individual actions rather than by Government action that this can best be improved. Anyone that wants work done had better get someone to do it, and people with money to spend should spend it rather than hoard it up. Government action is not very efficient as a rule, but can undoubtedly be of assistance in getting over the present crisis. To rely too much on it, however, is to court disaster. Most of its schemes cost money and, with taxes at present rates, it is difficult to see how they can be increased without doing more harm than good. These have already crippled industry, and taxation already takes so much out of a business that the balance left is only a slight incentive to put forth the maximum effort and initiative to develop the new lines of business which are most urgently wanted at the present time. Human nature being what it is, there is a feeling that if business comes easily well and good: if lost it does not much matter, since if the business were to result in a loss the firm would have to stand the loss, and if in a profit, most of this would be handed over in taxes; so why worry, therefore, about new business when the only thing certain is that the profits, if any, will be small?

To increase taxation further in order to put forward schemes to absorb labour is likely to increase rather than decrease unemployment, and the number and nature of schemes that the Government can utilize without increasing taxation are strictly limited, and not in themselves nearly sufficient to cope with the problem. Therefore, above all, we want the principle of self-help and the spirit of Christianity, which, if really and universally prevalent, would soon solve all our financial troubles without devising fresh schemes of payment, Whitley Councils and the like, which are of use in making a little Christianity go a long way and without that little would fail altogether.

In the meantime, it behoves us all as individuals to do what we can to minimize the evils of unemployment and to try to avoid placing the burden on the Government. If we are employers we can keep a full body of men on, say, two-thirds time, instead of two-thirds of the employees on full time and the others off altogether; we can get plant into first-rate condition, develop new methods and articles of manufacture and work up stock, when there is any reasonable chance of this being utilized later even at a loss, though of course there is a limit to this. We must approach the limit as closely as possible. If employees, we can help by doing our work in such a manner that other men are not kept out of employment by reason of our work being left undone or delayed, and by using our brains more, and finding out work that can be done with advantage.

It is no sinecure to be a foreman in a workshop to-day with about 20 men available for work that is only sufficient to occupy 10, and if any man can find a necessary job that he can tackle without too much supervision he will earn the thanks of his foreman by pointing this out, even though the foreman may forget to thank him.

Throughout all these transactions the best guiding rule is the Christian precept, i.e. to consider the other man, and it is significant that a principle often associated chiefly with church-going should have so many, in fact I am inclined to say its main, applications in purely secular transactions.

For instance, the intangible "spirit of Christianity"—I am not talking of creeds or beliefs—has little to do with the volume of sound in a church anthem, but it affects the price of potatoes and electric light, the safety and wearing properties of a motor car, and the rent of a house. It enables capital and labour to be mutually helpful, and its absence leaves them mutually destructive. I know no other principle so far-reaching and comprehensive in its effects on human affairs.

I will now pass on to the second part of my Address, dealing with relativity, a principle the bounds of which are not yet fixed, but which is having a most profound and widespread influence in the world of physics.

Briefly, whilst the principle may be difficult to define in non-mathematical symbols, it may be said to do for a wide range of physics what the principle or law of the conservation of energy does for that section of physics which deals with the characteristics and the utilization of energy. That is to say, it is a great generalization from which many effects, that without this might be obscure and difficult to link up with other effects, can be predicted and defined with ease, even though a connection has long been suspected. For instance, it links up gravity and inertia, which it shows as different aspects of the same thing, and it indicates that time and space are not fixed, unchangeable standards, and are not independent of one another but constitute another instance of different aspects of the same thing. As an illustration, although it would not be advisable to push this too far, in measurement we speak first of, say, a foot length; this is made more complete by saying a foot by a foot, i.e. a square foot, this in turn being made more complete by considering a square foot by a foot long, i.e. a cubic foot. This may be further extended by, say, a cubic foot a year long, which is similar to what is done by relativity.* This has certainly a peculiar sound, but is all right if considered quickly; if there is any hesitation, second thoughts may suggest doubts as to whether it really defines anything. Still further consideration, however, rather supports the first. A searching analysis has shown that we really know nothing of time apart from some measurement of distance; a clock finger, for instance, or a clock pendulum.

We have other time-keepers, such as the sun, moon, etc., and even a sort of atomic clock, or, again, a rough guide in the growth of plants, but all these are in terms of distance.

It may be that some will think they can gauge time by their sensations or feelings, but if a man can go more or less leisurely through the events of his lifetime whilst falling from a second-story window this will be recognized as an extremely variable quantity. As a matter of fact there is no such thing as time apart from space, and a mathematical formula connecting the two has been discovered which enables the principles of relativity to be tested and their results extended and predicted. Time being not a fixed invariable quantity, our previous ideas of simultaneity are to that extent illusions, and our "now" can no more be now at other parts of the universe than this end of the room can be the opposite end. Time being in the nature of a dimension our journey "down the river of years" is thus something more than a poetic fancy, our journey through life being literally a journey which, so far at any rate, we appear to travel in one direction. In this respect, however, we only match our master clocks, such as the moon, which journeys steadily around the earth and always in one direction. Other results follow, or at any rate appear practically certain, from principles of relativity.

It is reasonable to suppose that anything that can be measured has a beginning and also an end, otherwise it seems doubtful if measurement has any meaning at all. The universe and space itself are thus not infinite, and time, being a part of it just as much as are height and width, is thus not unlimited. It does not follow from this that there is no such thing as infinity, but that there is no such thing as infinite space, since we think of space in miles, or light-years or some such unit of measurement, and to measure infinity at all is like measuring the weight of a tramcar by means of the taste of an orange. It also follows that there is no such thing as two infinitely long parallel straight lines, even from a theoretical point of view. I think someone has called the postulate of two infinitely long parallel straight lines a "meaningless noise," and it seems also to follow that all "straight" lines are really curved and would meet somewhere, as do lines of force from a magnet.

A further extension of our ideas follows as a result of our consideration of relativity. We cease to think, for instance, of things falling as the result of gravity. Considered from the independent point of view of relativity, what happens is a relative change of position of certain elements and the redistribution of energy that inevitably follows from, or rather accompanies, this alteration of position.

The theory of relativity results from the physicist's dislike of the idea of action at a distance. This looks to him too much like the case of an engine with cylinder, piston and crankshaft all complete except for a connecting rod. If the engine works he believes there is a connecting rod, even if he cannot see it. In the matter of the action between two magnets some distance apart, the idea of action at a distance gave way to action through the medium of the ether and lines of force, this in turn helping to build up the idea of continuity of all physical actions. In other words, in some way all things are connected, and apparent separation or discontinuities are really only a variation in some whole.

From that we begin to think of things, formerly considered to be separated by space, as now connected by space. That is to say, there is no such thing as separation, the universe being one continuous whole; what we refer to as "things" being local variation or singularity in this whole. Things or events are, however, also separated by time. If the idea of continuity is as universal in its application as is suspected, then past, present, and future must be connected in some way. Moreover, since all things are apparently interconnected, may it not be that time is connected with space in some way? Further consideration shows that time and space are inseparable and that time without space is meaningless. Minkowski, I think, found a mathematical expression linking up time and space in the form of a partial differential equation so that the effect of a variation in any one term on the other factors in this equation could be calculated, time being exactly equivalent to a dimension in this formula. This does not dispense with time any more than it dispenses with distance, but

* In relativity formulæ, $\sqrt{\ }-1ct$ becomes equivalent to a dimension, t being the unit of time, and c the velocity of light (186 330 miles per sec.).

indicates that they are connected, and that they vary with position and motion. It is curious that when Minkowski and Einstein took up the study of relativity they found a geometry of four dimensions already evolved and worked out to a great extent, by Gauss I believe, and extended to n dimensions by Riemann.

It may have seemed futile at that time to develop a theory of geometry in four dimensions when of course everybody knew that there could not be more than three, but it proved of immense use a few years later.

Mathematics, which is really a sort of crystallized rigid logic, has the advantage that a base can be assumed and results worked out from it that are inevitable from the base assumed, independent of whether the results represent anything real or not.

In human affairs this rigid logic does not apply to any great extent. It is, in fact, like extrapolation from a plotted curve and therefore to be mistrusted, as if carried far it is probably incorrect, on account of the introduction of some other factor not contained in the original basis.

The development of the electron theory concurrently with the relativity theory still further widens the outlook of science on physics. It has been discovered that what is known as mass (weight or inertia) is really a measure of the energy contained in that mass,* and that this energy is enormous, and out of all proportion to the energy that we utilize in our steam engines, boilers, etc.; all we are actually able to utilize at present is a very weak resultant which becomes available by our manipulation of the power-producing materials. This resultant is altogether trivial compared with what we know is really contained in anything having mass in the form of atomic energy.

Now that we know this energy is actually there, it is a practical certainty that we may eventually be able to liberate it; but, if we have not by then discovered how to control it, I am afraid the prospects are of a sudden change in our relative outlooks, if there is any outlook left.

A further point in connection with the electron theory is that it is now known that the atom has a nucleus, with electrons circulating round it, thus forming a miniature solar system. Now a molecule appears inconceivably small to our senses; it is practically nothing so far as we can see. An atom, therefore, which is only like a fragment of a molecule, it seems almost a gross exaggeration to describe as "half nothing." And yet this is known to constitute a miniature solar system, an idea which, a few years ago, would have been too far-fetched even to ridicule. But here comes rather a curious point. About 30 years ago I read a number of so-called occult books. Amidst a lot of loose and many demonstrably wrong statements there was one that occurred in, at any rate, the majority of these books, to the effect—to quote Sinnett's book on esoteric Buddhism (1885, page 190) —"As it is below, so it is above, wrote the early occult philosophers, the microcosm is a mirror of the macrocosm." (Microcosm means, of course, the minute and macrocosm the universe.)

Sinnett's book is, of course, only a matter of 36 years old, but the quotation agrees exactly with similar quotations I have seen in much older books, and the original appears to date back to something of the order of thousands of years ago, but is there a clearer summary of the electron theory to-day?

One word more about the electron theory as extended by relativity—it will be noted that all the effects by which we recognize matter are now accounted for by the effects of energy—the mass of a body, for instance, being equivalent to a measure of the energy contained in that body, so that there is an increasing tendency to deny the existence of matter at all.

I do not think this justified, my own opinion being that both exist, but that we know nothing of either without the other. I would define matter as "that which makes energy manifest," and energy as "that which makes matter manifest."

* mc^2, m being the unit of mass, and c the velocity of light (186 330 miles per sec.).

EAST MIDLAND SUB-CENTRE: CHAIRMAN'S ADDRESS

By T. P. Wilmshurst, M.B.E., Member.

(*Address delivered at* Loughborough, 11*th October*, 1921.)

I propose to give in this address a brief review of the developments which have taken place in recent years and are now taking place in the public supply industry, both to cheapen the supply and to render such supply increasingly reliable; and it is convenient to fix some date for the commencement of such a review. I therefore take as a starting point the Presidential Address * delivered in 1910 by Dr. Ferranti.

Dr. Ferranti commenced by calling attention to the present wasteful methods of converting the energy of coal into useful work, the loss being estimated at 90 per cent. In addition, we dissipate nearly the whole of the valuable by-products, consisting principally of fixed nitrogen, which could be employed to increase the return of food-stuffs from the comparatively small acreage of land under cultivation.

He next pointed to the large expenditure of labour in raising, distributing, and burning coal, and also in clearing up the dirt produced by our present methods of using coal, and outlined the ideal method of employing the coal resources of the country. This was, to concentrate the whole transformation of coal into energy at a comparatively small number of large generating stations, and thence to distribute the electrical energy to supply the entire light, heat, power, and chemical energy required for the industrial and domestic needs of the country.

In order to supply electricity for all purposes, Dr. Ferranti estimated that it would be necessary, amongst other things, to have an efficiency of conversion of not less than 25 per cent. Assuming this efficiency instead of 10 per cent as at present, the annual consumption of coal would be reduced from 150 million tons to 60 million tons.

He then discussed the gas turbine, but was not in favour of it. He preferred what he called the "steam gas turbine" in which steam at a high temperature is used throughout the process of conversion into work.

He next dealt with capital cost, and finally came to the conclusion that it would be possible with a load factor of 60 per cent to generate electrical energy at a cost of 0·1145d. per unit, including capital charges. The price of coal was assumed to be 10s. per ton, but the cost was credited with fixed nitrogen by-products for agricultural purposes to the value of 8s. per ton.

We have not yet arrived at these figures, as the war has played havoc with both our capital and working costs, but we are already devoting attention to the concentration of large units in main stations. Generating sets of from 10 000 to 25 000 kW rating are an everyday practical problem, and I am convinced that the visions of 1910 will be realized in our lifetime.

* *Journal I.E.E.*, 1911, vol. 46, p. 6.

I would recommend all members to re-read Dr. Ferranti's address in the light of present knowledge.

Mr. David Brownlie, an expert in fuel combustion, has recently pointed out that about 90 million tons (or 47 per cent of the total home consumption of coal) are used for raising steam. Although a boiler efficiency of 75 per cent can be obtained, over 90 per cent of the boiler plants of Great Britain are at present worked in a rough-and-ready manner, no instruments such as steam meters, draught gauges, combustion recorders, etc., being used. An investigation by Mr. Brownlie's firm of over 400 steam-boiler plants showed an average efficiency of only 58 per cent. This efficiency, in comparison with the possible 75 per cent, means a dead loss of 20 million tons per annum, caused solely by the failure to adopt elementary and well-known methods. The obvious remedy is the concentration of all power supply in large, modern power stations.

The Report of the Coal Conservation Sub-Committee published in 1918 also laid great emphasis on our wasteful methods. It is a sad admission that the overall efficiency in an average power station is only about 10 per cent; in other words, only about 10 per cent of the heat energy in the coal appears as electrical energy at the switchboard. The best figure obtained in the largest and most modern plants in this country is only about 18 per cent. In 1919 Dr. Ferranti gave his reasons for believing that we may attain an overall efficiency of 28 per cent. His suggestion, amongst others, was progressively to heat the feed water from the temperature of the condenser as nearly as possible to that of boiling water, by abstracting, from various places along the turbine, steam which had done more or less work. This in turn would involve the abandonment of the water economizer, as it would supply water to the boiler at nearly the full temperature of evaporation.

The boiler house offers the greatest scope for improvement. A large, modern water-tube unit consisting of boiler, superheater and economizer can, when clean, and with good coal, show an efficiency of 85 per cent. This figure, however, is seldom, if ever, attained in practice as there is usually a considerable difference between the efficiency on test and that during operation.

The chief factors affecting daily operating efficiency are:—

(1) The human element.
(2) Load factor.
(3) Lack of facilities for the scientific control of efficiency.
(4) Variability of the coal used.

Not long ago the boiler house was looked upon as

a dirty place to be avoided. Now, however, with automatic coal- and ash-handling and automatic stoking, there is no reason why a boiler house should not be almost as clean as a turbine room. Further, one is amply justified in using the best class of brains and experience in the running of the boiler house.

At Derby a skilled steam engineer devotes his whole time to improving the efficiency of the boiler plant. A complete equipment of distance thermometers has been installed, showing at a glance the steam temperature of each boiler, the inlet and outlet temperatures of the economizer, and the flue-gas temperatures. Daily tests are made of the hardness of the make-up water, and of the quantity of CO_2, and a weekly summary report is prepared. All the coal brought in and ashes taken away are weighed and recorded, and by constant attention to detail the coal consumption has been reduced from 5·1 lb. per unit generated in 1915 to 3·07 lb. in March 1921.

While this is a good figure compared with other stations of similar size working under similar conditions, we shall not be content until we have reached a figure not exceeding $2\frac{1}{2}$ lb. per unit generated. The saving between 3·62 lb. (the figure of the previous year) and 3·07 lb. amounts, with our last year's output, to more than 5 900 tons.

All steam engineers are watching the possibilities of oil fuel, and the recent coal strike has emphasized these possibilities. Most of the oil-fuel installations carried out during the strike were necessarily of a makeshift character. At the Lots Road power station, Chelsea, 24 boilers were fitted up and materially assisted in the preservation of the supply to the Underground Railways. The price of oil was about £5 5s. per ton, although in pre-war days it was, I believe, as low as £2 10s. If the price of oil were to drop to £2 per ton, and if coal were to remain at its present price, I believe a good case could be made out for using oil fuel.

Oil contains from 18 000 to 19 000 B.Th.U.'s per lb., as against 10 000 to 11 000 B.Th.U.'s for coal. Further, all the expense of mechanical stoking and coal- and ash-handling is avoided.

The only official statement I have seen is in connection with the Leeds Tramways. Mr. J. B. Hamilton, the general manager, reports that 6-hour tests were made, with both coal and oil, eight boilers being fired with oil fuel. Ten tons of oil were used, giving a consumption of 1·98 lb. at a cost of 1·115d. per unit, against a coal consumption of 2·859 lb. at 0·560d. per unit, at last year's prices. The price of oil was taken to be £5 5s. per ton. Mr. Hamilton's conclusion is that the price of oil would have to be £2 17s. per ton to compete with good coal at £1 16s. per ton.

I do not propose to go further into details of oil burning, except to say that there are three main systems now in use:

(1) The steam atomizing system.
(2) The air atomizing system.
(3) Mechanical atomization by pressure.

The objection to (1) is the amount of steam used, about 5 per cent of the total generated, though it is probably the simplest system to install.

Air is not often used, on account of the initial cost of the compressing plant.

The third system, although it involves the use of pressure pumps, is the one most in favour to-day. There is no waste of feed water as in the steam system, and, as there is a closed air circuit, oils which cannot be used in any other way can be dealt with owing to the greater temperature to which the oil can be heated in a closed system. Boilers can be kept much cleaner over long periods when oil is used than when coal is employed. A present difficulty is the shortage of tankers.

I might here refer to the increasing use of balanced draught in large plants. Balanced draught simply means that, with a given pressure under the grate, the suction draught is reduced to the minimum necessary to lift the products of combustion through the flues. Thus there is practically a balance in the furnace, the forced draught overcoming the resistance of the grate and fire bed.

The use of turbine-driven steam pumps also makes for economy, as 97 per cent, or practically the whole of the heat in the exhaust steam, can be utilized in heating the feed-water.

Another point which deserves mention is the prevention of corrosion in feed pipes and boiler drums, effected by the exclusion of all air from the feed-water system, thus causing it to operate on a closed cycle. Dissolved air in feed pipes is sooner or later bound to lead to trouble.

Some large stations in America have adopted the practice of taking the hot air used in the ventilation of the alternators and passing it through an air trunk to the underside of the boiler grates, but I am very doubtful if the added efficiency compensates for the extra expense and complication.

I might refer in passing to the Bonecourt boiler, which is usually fired by waste gases, a gas jet being applied to each tube. The boiler is equally suitable for oil firing. Each unit comprises a boiler, superheater, and economizer, and can be worked to a final steam temperature of 700° F. The boiler shell for 20 000 lb. evaporation is only 6 ft. in diameter by 18 ft. 6 in. long. The makers claim to have obtained a thermal efficiency of 92·7 per cent. No brick setting, flues or tall chimney are required.

Powdered fuel is also an interesting possibility, but at present very little information is obtainable. The experiment which is being tried at the power station at Hammersmith will be watched with interest.

I propose to limit my remarks on turbines to one or two developments for securing greater reliability. The efficiency of the turbine itself is so high that we cannot look in this direction for much improvement on present designs. The greatest source of waste is the transference of heat from the exhaust steam to the cooling water, some 60 per cent of the heat units being lost in this manner.

Blade stripping is now reduced to a negligible quantity. It was formerly claimed by the advocates of the impulse turbine that in the reaction type it was necessary to sacrifice reliability in order to obtain efficiency by reducing the radial clearance to a dangerous limit,

and that the blading was too flimsy for safety. This was to a certain extent true, and these objections have now been overcome in the Parsons turbine. In the early days a certain amount of blade stripping occurred when priming or a heavy short-circuit caused the shaft to whip. Now, a large radial and fine axial clearance very largely tends to prevent stripping.

A further simplification of the turbine auxiliaries can be obtained by the adoption of the "multi-jector" air pump which contains no moving parts. Great advances have been made by increasing the sizes at higher speeds, and a 10 000-kW set running at 3 000 r.p.m. is quite an everyday proposition. In fact, I believe one firm has constructed a 18 500-kW machine running at this speed. The consumption at this speed is appreciably lower than at 1 500 r.p.m., and the capital cost also should be appreciably lower.

I do not propose to discuss the steam conditions necessary for maximum efficiency, as they have frequently been discussed in various papers.

Steam pressures up to 250 lb. per sq. in., and superheats to give a total steam temperature of 700° F., are now quite common, and these, coupled with a vacuum of 29 inches, enable a high degree of economy to be obtained. The best result of which I have personal knowledge is a figure of 9·9 lb. of steam per kilowatt-hour obtained on one of the 10 000-kW sets at the Carville power house of the Newcastle Electric Supply Co. I understand that at the new Tees-side station of the same company a steam pressure of 450 lb. per sq. in. is to be used.

While a high degree of vacuum is necessary to economy, Mr. E. Cross, of Rotherham, points out that previous to the advent of high steam pressures a high degree of vacuum was much more important, but that, to arrive at the lowest cost to the consumer, the question of vacuum now requires careful consideration.

Other things being equal, a greater heat-drop is available as the vacuum is improved, but the efficiency of the turbine itself falls slightly, due to the increased friction caused by the increased moisture, and to the greater leaving losses in those cases where practical limitations govern the length of the blades and the size of the exhaust area.

An increase in the vacuum from 28 to 29 inches doubles the volume of the steam at the exhaust, and if the same blading were used the leaving losses would be increased. An increase in the vacuum necessitates a large quantity of cooling water, and therefore more power is taken in driving the circulating pump and the air pump, and these items may become so appreciable as to result in an actual loss of coal.

To those who are interested in these matters I would recommend a study of the papers by Mr. Shaw,* Mr. Baumann,† Mr. Robinson,‡ and Mr. Cross.§ Further turbine developments include the tendency to divide large turbines into high-pressure and low-pressure cylinders, the latter being of the double-flow type to facilitate the evacuation of steam into the condenser.

* *Journal I.E.E.*, 1919, vol. 57, p. 73.
† *Ibid.*, 1921, vol. 59, p. 565.
‡ *Proceedings of the Incorporated Municipal Electrical Association*, 1920, p. 75.
§ *Ibid.*, 1921.

A further tendency in large plants is the duplication of the circulating pumps, one being driven by electric motor, and the other by a small turbine exhausting into the main condenser.

In several new plants the external air filter, whether of the wet or dry type, is being abandoned in favour of an internal air cooler; a stack of cooling-water tubes is built into the air duct, and the air circulates in a closed circuit.

Another factor which makes for increased reliability in the alternator, or at any rate limits the damage due to electrical breakdown, is the adoption of some form of circulating-current protective gear. It is obvious that in the event of the stator winding breaking down the main overload oil switch is useless. A large alternator rotor takes anything up to half an hour to come to rest after the steam is shut off, and, with the large volume of air now used for stator ventilation, a breakdown of insulation at one point may easily lead to the complete destruction of an alternator before it can be shut down. The operation of the circulating-current system depends on the equality under normal conditions of the currents passing in the line and the neutral side of each phase, and on their inequality when an internal fault occurs. Similar current transformers in the line and star sides are connected so that their equal secondary currents circulate and leave the protective gear undisturbed. Any variation in secondary current, however, due to a fault, finds its way through the relay and causes it to trip and open the main switch by means of a shunt trip-coil. This protection is usually combined with a field-suppression switch which reduces the stator voltage and so minimizes destructive arcing. Similar circulating protective gear can be arranged for large step-up and step-down transformers.

Recent developments in cable manufacture have been chiefly in the direction of increasing the reliability and in researches as to the possibilities of still higher voltages. Investigations by Prof. Jona in Italy and Mr. O'Gorman in this country showed that the potential gradient through the dielectric of an extra-high-tension paper cable is not regular, but that it is steeper in the layers nearest to the core. Many researches have been made to produce an even potential gradient in cables built for the higher pressures.

The protection of feeders against the effect of short-circuits has reached a high pitch of perfection. Where two or more feeders are in parallel, perfect and instantaneous control can be obtained by the employment of the well-known Merz-Price gear, which involves the use of a pilot cable. The later development of the Merz-Hunter split-conductor protection obviates the use of a pilot cable. For three-phase cables run singly, I am of the opinion that overload protection with an inverse-time element is quite sufficient for all ordinary cases.

Investigations of the performance of cables when laid show that the temperature-rise is considerably affected by the method of laying. Experiments on a 0·5 sq. in. cable at a current density of 1 500 amperes per square inch showed the following temperature-rises after 10 hours' running:—

(1) Armoured cable laid direct: 48 deg. F.
(2) Lead-covered cable in asphalt trough: 53 deg. F.
(3) Lead-covered cable laid solid: 85 deg. F.
(4) Lead-covered cable drawn in: 98 deg. F.

To judge from these results, the worst arrangement is a number of cables drawn into a nest of pipes. For the same temperature-rise an armoured cable laid direct will carry approximately 30 per cent more current than a corresponding plain lead-covered cable drawn into a dry stoneware pipe. British cable-makers have been able to supply satisfactory three-phase cables for 6 600, 11 000, 20 000, and now 33 000 volts. A considerable quantity of 33 000-volt cable is now being made and laid for interlinking purposes.

It is doubtful whether a pressure exceeding 33 000 volts is required in this country, although one leading firm is now advertising a three-core cable for 60 000 volts. A cable of this size is almost too unwieldy to handle. There is no difficulty in constructing three single-core cables with 66 000 volts between them and 38 000 volts to earth. I understand that the Union d'Electricité of Paris is about to lay some single-core cables for 66 000-volt working, but I believe that there are technical difficulties regarding the use of such cables for long distances.

One objection to still higher pressures is the dielectric loss, which increases as the square of the pressure and may become a serious item at a pressure of 66 000 volts. One leading firm in this country has recently accepted a contract in which the dielectric loss will not exceed 1·5 kW per mile with a conductor temperature of 140° F.

Mr. Pearce of Manchester has pointed out that 66 000-volt cables are not likely to be profitable unless the load factor is at least 60 per cent. Theoretically, extra-high-tension cables at these very high pressures should preferably not be armoured, as the armouring appreciably increases the impedance of the cable and causes an additional loss due to hysteresis and eddy currents. Mr. Pearce calculated that on a 0·15 sq. in. cable at 60 per cent load factor, the I^2R losses would be about 129 000 units per mile per annum, and the dielectric losses 100 000 units, so that the latter cannot be considered to be negligible. Further, to allow for the dissipation of heat in 33 000-volt trunk cables, they should be laid not less than 1 ft. apart. This seems to be an additional argument against the super-station, as it will be a matter of great practical difficulty to find room for a large number of trunk feeders in one trench.

As regards the immediate future development of electricity supply in the East Midland area, I must speak with reserve, as the whole question will shortly be considered by the Electricity Commissioners.

I am not in favour of one super-station as generally understood, as the costs and losses on the trunk lines, at present prices, will show no saving over locally generated energy at the more efficient of our existing stations. Links between existing stations would undoubtedly be a convenience, but if used simply for stand-by or week-end purposes they would not justify the expense: unless they were used for the constant transference of large amounts of load at a load factor approaching 50 per cent, no saving could be shown by their use.

In the development of rural areas we are far behind such small countries as Denmark. The reasons are probably two-fold; the parochial limits of present areas of distribution, and the innate opposition of land-owners and tenants to the erection of overhead transmission lines. The first of these objections will to a large extent disappear under the schemes for developing large areas now before the Electricity Commissioners.

It is obvious that only overhead distribution for scattered rural districts will be financially possible, and that expensive substations and switchgear will be superseded by pole-type transformers and overhead fuses and isolating links.

As regards generating units, I am of the opinion that for the requirements of this area the 10 000-kW unit will be a most convenient size, as plants of this capacity can be constructed for 3 000 r.p.m. and are therefore as efficient as larger sets run at 1 500 r.p.m., while the capital cost per kilowatt should be as low as in the larger sets.

The voltage regulation on interlinked schemes offers an interesting problem. Where large stations are interlinked it is obviously difficult for one to raise its own voltage to accommodate another without affecting the phase displacement, on account of parallel operations.

An ingenious arrangement to meet this difficulty has recently been put on the market by the British Electric Transformer Co. The principle adopted is the provision of a supplementary regulating transformer which operates on the low-tension side of the main step-up or step-down transformers. Between the tapping and the end of each phase of the main transformer is connected the primary winding of a small transformer, the secondary windings of which are provided with tappings connected to a regulating switch, the latter being provided with a reversing switch. In series with the primary winding of the small supplementary transformers is connected one winding of a second small transformer, the other winding of which is interconnected with the whole or part of the secondary of the first small transformer via the regulating switch. The arrangement provides for 10 steps, and the voltage in this particular instance can be raised from 9 750 to 10 750 volts. The advantage of this arrangement is that the regulating switch is connected to a winding which is electrically separated from the main winding of the supply. This winding can be designed for any suitable low voltage and thus a cheap, reliable switch can be used.

Amongst the most interesting of modern developments is the mercury-arc rectifier which is now emerging from the experimental stage. This apparatus is used for the transformation of three-phase alternating current to direct current. As it is a purely static apparatus it is likely to become a serious competitor of the rotary converter. The mercury arc when operating in a vacuum has the peculiar property of permitting the passage of a current in only one direction. For

technical reasons it is usual to construct the plant as a six-phase rectifier.

The advantages of this type of rectifier are: The efficiency over a wide range is constant at about 93 per cent; the power factor approaches unity; it is stationary and will run unattended for long periods; it is unaffected by momentary short-circuits; it occupies less space than a rotary converter; its inherent voltage regulation is good; it is easily started and re-started; it is less than half the weight of a rotary converter; the frequency has no bearing on its operation; and it is noiseless. The makers, Messrs. Brown, Boveri and Co., have supplied about 150 of these plants, and they are being installed to the extent of several thousand kilowatts on the Chemin de Fer du Midi, France.

In conclusion I propose to refer very briefly to one or two new developments in electric lamps. The "Pointolite" lamp and the gas-filled projector lamp are beginning to take the place of the carbon arc lamp for lantern work of all kinds, including cinema work.

The latest achievement is the neon lamp. Hitherto the smallest tungsten lamp consumed about 20 watts, and there are many places where a lamp with a still smaller power consumption meets the case, such as passages and porches, bedrooms, etc. As the lamp runs on open circuit it can be fixed across branch fuses, and will thus instantly show which fuse has blown. The bulb has no filament, but contains two metallic electrodes, an anode and a cathode. The anode is connected to the lamp contact by which the current enters, and the cathode to the contact by which it leaves. On switching the lamp on, a discharge or ionic bombardment takes place. This is visible as light of an orange yellow appearing as a luminous haze over and about the cathode. The light is particularly rich in red and yellow rays and can therefore be seen at a distance. The life of the lamp is limited only by the blackening of the glass. This type of lamp may lead to important developments in the future.

I trust I have said enough to show that the electricity supply industry is not stagnating, and that, with the cordial co-operation of manufacturers, contractors, and supply authorities, we may look forward to a wide extension of the possibilities of electricity in the near future.

LIVERPOOL SUB-CENTRE: CHAIRMAN'S ADDRESS

By G. H. Nisbett, Member.

(Address delivered at Liverpool, *7th November,* 1921.*)*

I have taken this opportunity to draw attention to what I believe to be an urgent matter, namely, the need for the display of more enterprise in seeking for the extension of electricity supply, and particularly new lighting consumers.

Everyone is, of course, aware of the present unprecedented slump in trade. Electrical interests were perhaps the last to feel the depression, but it is now with us to a serious extent and it is questionable if we have yet seen the worst. Manufacturers, wiring contractors, and even electric supply authorities are finding that their business has fallen off in an alarming degree, and it therefore behoves us all to see if everything is being done to obtain all the business possible, and to consider whether some of the methods and customs hitherto in force cannot be scrapped or modified so as to make what we have to offer still more attractive to the potential consumer.

As time goes on, that part of the electrical industry connected with power and lighting supplies is more and more dependent for its prosperity on the enterprise of the electric supply authority and the wiring contractor, and it is as a manufacturer who is largely helpless to influence the volume of business to be done that I make my appeal.

It is only to the power and lighting consumer at present unconnected that we can look for new business, apart from the supply of lamps. Now it seems to me that the power-supply side of the business has been unduly boomed to the neglect of the greater possibilities of lighting, and power supply which was originally regarded only as a means of filling up the valley in the lighting-load curve has now, with most stations, become the backbone of the business. For a good many years now supply managers have concentrated on bulk supply, and particularly before and during the passing of the 1919 Electricity (Supply) Act the Press and some authorities talked as though the provision of electricity on tap from mains throughout the whole country was economically feasible, and as though, if it were done, it would make all the difference to manufacturers between being able to compete abroad and becoming bankrupt. I do not say that a cheap supply of power will not help to reduce manufacturing costs, but we can see that it is not a paramount factor when it is borne in mind that the cost of power to the average factory, eliminating exceptional cases such as rolling mills, etc., is no more than from 1 to $2\frac{1}{2}$ per cent of the cost of the finished product of that factory. It is evident, therefore, that the question of power supply

need not be considered from any utopian point of view or from that of furthering any national object, but only from a purely business outlook.

No doubt the large number of units that can be sold to the consumer of power, compared with the individual lighting consumer, is an attraction in itself, but it has to be remembered that it is not always the large consumer who yields the most profit, particularly if he has to be given wholesale terms. The profit obtainable from power supply will always be a strictly limited one, because the saving effected in coal, labour, and capital for plant at a central station, compared with power generated locally, is largely off-set by the cost of capital charges for, and losses in, transmission. Moreover, the power user always has the option of putting down his own plant, and can generally work it without difficulty, so that the profit obtainable on the turnover can only be the difference in cost between a larger and a smaller business, less delivery charges.

Of course there are small power consumers and those with intermittent loads to whom generation of their own supply presents increased difficulty, and from these a higher price can be obtained, but then their load factor more nearly approaches that of a lighting consumer.

Now the lighting side of the business seems to be in a very different position. In the factory the cost of power supply is the prime consideration, and convenience unimportant, while in a private house convenience comes easily first and cost is quite secondary. Moreover, the consumption of energy by the average lighting consumer is so small that it is out of the question for him to put down his own plant. Electricity as a means of illumination stands without a rival—one cannot imagine a single dwelling house being without a supply if only the initial cost of wiring could be overcome—all new houses, even workmen's cottages, are wired as a matter of course, so that the daily cost does not stand in the way of even the poorest of us. This is evident from the fact that many districts have raised their price for lighting to 10d. and even 1s. per unit without the loss of a single consumer. This is not surprising when one considers how small a proportion of our total household cost is due to that of artificial illumination. The average householder probably spends more in a year with his milkman or his tobacconist than he does with his supply authority.

It follows that electric lighting being so much more of a monopoly than power supply, very much higher profits on the turnover can be obtained, and generally are obtained, so that I am of opinion that this fact has been presumed upon in many districts to subsidize power supply at the expense of the lighting consumer. How can one justify charges from the same source of 7d. and 8d. per unit for lighting, and 2d. per unit for heating and cooking, bearing in mind the relative load factors and making every allowance for diversity, or a similar difference in charges between a lighting supply with a load factor of, say, 12½ per cent and a factory supply with one of 25 per cent where the load is simultaneous for some period daily in the winter time?

There are supply undertakings purchasing their current in bulk at prices from 2d. to 2½d. per unit in the position, relative to the generating authority, of power consumers. These undertakings are in turn selling retail to the consumers at anything from 6d. to 10d. per unit. On the one hand, out of, say, 2½d. per unit the raw material, coal, oil, etc., has to be bought, and wages, technical and other management expenses, interest, depreciation on all the plant and buildings and often on the trunk mains have to be found. On the other hand, out of a difference of anything between 3½d. and 7½d. per unit there has to be found only business management of a simple kind, repairs, interest and sinking fund on the network of cables, meters, and perhaps some transformers—it seems evident as to who has the best end of the stick. We have here an illustration of why only a comparatively poor percentage of profit can be obtained on power supply. The generating station has to sell cheaply because otherwise the distributor will put down his own plant, whereas the distributor gets a good profit because his customer has no practical alternative but to pay the price if he wishes to use electricity as an illuminant.

I hope that I have at least said enough to call the attention of supply authorities to this question, and perhaps induce them to take steps to give the potential lighting consumer some added encouragement to wire his premises and use the supply.

I hope, too, that it is clear I am not for one moment suggesting the neglect of power supply, but rather the cessation of the neglect of the lighting side of the business which I believe has taken place.

Now, if we come to consider it, the average man gets very little encouragement to become a consumer. The supply is given him inside his front wall and he is left almost entirely to his own devices as to how to utilize it. If he does make up his mind that he is so keen on electric lighting that he will go to some trouble about it, he applies to the supply authority and is then given a formidable form to fill up, and perhaps a set of Wiring Rules which, if he reads them, lead him to believe that electricity supply is almost as dangerous as the introduction of T.N.T. into one's house.

He is told that he must get a contractor to wire his house and he is left to make the best bargain he can, not knowing what he ought to get for his money, nor having any guidance in the art of illumination. This often results in a most unsatisfactory job, both in the quality of the work and in the distribution of light. I am not blaming the wiring contractor for this condition of affairs; he is the victim of circumstances. His business has always been the least remunerative of all the branches of electric supply, for the reason that anyone with or without knowledge, but possessed of a capital of £50 or more, can and often does start as a wiring contractor and, having cut prices and done a certain amount of shoddy work, goes bankrupt, then after an interval probably starts all over again.

To induce the very desirable and profitable lighting consumer to come on to the mains, it is necessary to see that he is saved from as much trouble as possible in doing so, and is assured of a sound installation at a reasonable price, with a suitable number and disposition of lamps. To ensure this I would suggest that the

supply authority should make themselves responsible to the consumer for the wiring of his house; that they themselves should quote him a price for his wiring and see it properly carried out, as regards both the quality of the work and the position and size of lamps. The authority would previously have made a list of approved wiring contractors in the district, that is, all those whom they know to do good work and have a competent staff. The authority should prepare a specification to which their wiring contracts would be let, having in mind durability and cheapness. Having obtained a consumer's order they should sub-let the contract without profit to themselves, to one or other of the wiring contractors.

Or, as an alternative, the authority should act as consulting engineer for the job, preparing a specification to ensure that, on the one hand, nothing but good material is used, and, on the other, that no unnecessary money is spent, bearing in mind that it is to the authority's interest to get the work done cheaply, while of course leaving the contractor a fair profit.

A printed list of contractors who are known to do reliable work would be given to the consumer, and he could be told to choose therefrom whom he would ask to tender, leaving him to place the order with the knowledge that he would be safe with anyone on the list. During the course of the work the authority should visit and inspect, and, on satisfactory completion, issue a certificate to the consumer on which the contractor should be paid. This advisory work should be free of charge, as the authority receive their remuneration in the subsequent business they will do with the consumer. There should be available at a central depot a selection of samples of fittings, such as ceiling roses, switches, lampholders, etc., of approved types, and it should be understood that contractors on the official list would use fittings of those makes or others equally as good.

Both these proposals ensure good work and the avoidance of unnecessary cost, but bearing in mind that the great deterrent to a large expansion in lighting business is the initial cost of wiring to the consumer, and that the suggestions made minimize but do not remove the difficulty, I have still another suggestion to make, namely, that the supply authorities should themselves pay for the wiring and make no initial charge at all to the consumer, recouping themselves for the cost, either by an addition to the price per unit or by a separate rent charge.

Many years ago I started the "free wiring" idea and was instrumental in forming a company for working it. It undoubtedly brought a large influx of new customers on to the mains of those authorities which adopted the system, but it broke down in practice because of legal difficulties. Now, however, that supply authorities have power to provide and let out on hire wiring and other apparatus, there are no difficulties in the way, and ample interest could undoubtedly be earned on the extra capital expenditure.

I seriously suggest to supply managers that they should carefully consider the possibility of offering to wire as far as the ceiling roses, or equivalent, any premises for which supply application is made to them, provided they are satisfied that there will be reasonable use.

I think it will be agreed that electricity supply is offered in anything but an attractive form, from the fact that a consumer is at present obliged to pay for such portion of the transmission system as happens to be on his premises, and if he rents his premises, as he usually does, in paying for the cost of wiring he does in fact make a handsome gratis present to his landlord, who, on a change of tenancy, obtains an increased rental because the premises are wired.

One can perhaps best realize what a really serious thing this is to the consumer when one considers that under the present system, the total capital cost to the electricity authority per lighting point connected to their mains averages about £2 5s., whereas the cost to the consumer of wiring from the main cut-out to the ceiling roses or equivalent costs to-day, say, 30s. per point. So that, of the total capital of £3 15s. (excluding fittings) necessary for complete supply, only 60 per cent is found for the consumer and the other 40 per cent he has to find himself. Now some of us remember that the first Electric Lighting Act gave companies a right to exercise their franchise for only 21 years, and that at the end of that time they were to be bought up at the "then value," and how financiers would not invest their money on so short a term. The period was subsequently increased to 42 years before progress could be made, and even now there are those who contend that the term is too short to allow of a sufficient display of enterprise. Now if those concerned in the finance of electricity supply took this attitude with regard to their 60 per cent proportion of the capital costs, can it be expected that a householder who is at the same time a business man will willingly spend his 40 per cent in face of the fact that he generally has his premises on only a short lease or a tenancy of a year or two, the law being such that from the moment he fixes his wiring its ownership passes from him and he, the tenant, has the use of it only during his tenancy and, when that ceases, has to leave it behind him without receiving even its "then value"?

Would anyone but an enthusiast spend his money under such circumstances? We can only wonder at the progress we have made under such a handicap, and at the extreme attraction that electric lighting must have over any other form of illuminant.

In addition to the expense referred to, the would-be consumer has, of course, to provide fittings; but while this means an expenditure of capital that it may not, in many cases, be convenient for him to find, yet it contains no element of unfairness as in the case of the wiring, because of course the fittings remain the property of the man who pays for them and he can remove them as he wishes.

By providing the wiring free of initial expense, the consumer's chief difficulty would be met, with results that would much more than outweigh the additional responsibility assumed by the electric supply authority.

I think it will be readily admitted that, if free wiring were offered, there would immediately be an enormous influx of new consumers and that the resulting business

would be of great value to the trade just now. The wiring so provided would, of course, remain the property of the authority, and its continued possession to them is secured by clause 23 (2) of the Electricity (Supply) Act, 1919.

Financial provision would have to be made to cover interest and depreciation on the additional capital as well as to provide for the cost of the removal or renewal of wires in the event of alterations to or rebuilding of premises. This cost would have to be passed on to the consumer, but it is in fact already borne by him when he provides his own wiring and, in addition, if he is a tenant or leaseholder, he needs to write off the whole cost in a period determined by his tenancy or lease. Therefore, the proposal that the authority should find the wiring instead of the consumer and charge him a commensurately higher price per unit for having done so, or alternatively a separate rent charge for it, would in fact cost the consumer rather less than he would pay *in toto* under the present system; the reason being that the cost both of money and of materials is less to the authority than to the consumer. The only possible risk the authority would incur would be that people who have obtained "free wiring" might cease to use electric light. This is a remote contingency, because we all know how few of those who have once had electric supply are willing to give it up again, and even this contingency could of course be measured in pounds, shillings and pence, and provided for either by slightly increasing the charge all round or by inviting the free-wired consumer to sign an agreement to take or pay for a fixed minimum supply for a period of years.

As to the charge that it would be necessary to make to cover the additional cost in this matter, it would seem that the average capital cost of wiring can be taken as being at the present time 30s. per point, with the prospect of early reduction. The annual charge upon this sum would be made up by interest at, say, 6 per cent, sinking fund at 2 per cent, and extra depreciation and contingencies not thereby provided at, say, 2 per cent; so that a charge of 3s. per annum per point would about cover the cost, or, if it were preferred, an extra charge per unit of about 2d. would on the average provide an equivalent sum.

Under the system suggested, consumers would still have, of course the option of paying for or providing their own wiring initially, or of purchasing it from the authority at any time, less an allowance for depreciation.

No appreciable addition need be made to the present organization, because the authority would, as a matter of course, let contracts for the wiring work just as they now do for their cables, turbo-generators and buildings.

The next point I would urge, in view of the stumbling block of cost, is the simplification of wiring. One has only to look at the Institution Wiring Rules to see how far complication has gone in what is after all a very simple business. If we bear in mind that the problem only consists of running a wire from a fuse to a switch, then to a lamp and back to another fuse, in such a way that the current is confined to the wire, we see how far the electrical engineer has gone in strangling himself with red tape.

We have been hopelessly handicapping our business for the sake of the fire insurance companies, and I suggest that all we are called upon to do is to give a reasonable modicum of safety, bearing in mind that perfection can never be reached, and that the attempt to eliminate the last element of risk can be too dearly bought. Both the consumer and the insurance companies ought to be well content with any reasonably safe system of wiring if electric lighting is used in substitution for gas, with its undoubtedly greater risk.

Of the various systems of wiring, the conduit system is probably the most costly of any, and to my mind much the most unsatisfactory in practice. If it is installed as perfectly as it theoretically should be, it still has inherent weaknesses owing to the severe handling the cable necessarily gets in drawing in, and to water condensation in the tubes causing rapid deterioration of the rubber-insulated cables. As a matter of fact, however, it is hardly ever properly installed; disconnected and, therefore, unearthed lengths of tubing are often used between floor and ceiling and as drops to switches; cables are drawn around acute bends and permanently stretched; sharp ends of tubes are left without bushes, and rust plays havoc with the cables.

I have seen cases in which a lot of money has been spent in installing the conduit system under the impression, as I think, that elimination of fire risk was thereby effected, and then the supply authority has shown its contempt of the whole thing by installing its apparatus under a wooden staircase and bunching the rubber-covered wires in tortuous heaps behind a wooden board on which their meter, etc., were mounted.

I am an advocate of either lead-covered wire throughout (the lead being bonded and earthed) or of going back again to the original system, namely rubber cables in wooden casing where otherwise exposed, and supported by porcelain cleats in such places as between floor and ceiling.

I believe the lead-covered system to be a better job electrically in every way than the conduit system, and infinitely more durable. It is also much cheaper unless the cost is loaded unnecessarily by providing armour or other protection to prevent the remote possibility of damage to the cable when buried in the plaster or laid between floor and ceiling. I think the wooden casing and cleated system to be still cheaper and sufficiently good, involving in use only a minimum of risk of fire and practically none to the person.

Whatever system be used, no necessary expense should be spared to ensure that the fuses are really efficient and of such a type that they can be relied upon to protect branch circuits against a dangerous excess of current. If this is done, there is no need to spend a lot of money in trying to ensure that conditions are made so safe that the fuse can never act.

Now the next thing that seems to require attention is the standardization of fittings, particularly wall plugs. Nothing is more annoying to the consumer than to find that the plug supplied with a new lighting or heating fitting that he has bought will not fit into any of his existing sockets. I even know of a case in which a householder has recently tried to avoid the

difficulty by going to the expense of having new plugs all of one make fitted throughout his house, and even now they are not interchangeable, much to his natural disgust.

If the British Engineering Standards Association cannot be persuaded to take up the matter promptly, I suggest that a Committee of the Incorporated Municipal Electrical Association should deal with the question in their own interests, for a great deal of revenue is at present being lost owing to this want of interchangeability of plugs preventing, for instance, an electric kettle or iron being usable universally in any socket throughout the house. Lampholders and lamp caps require similar attention, as it is not unknown now for a lamp to fail to go into the holder, or to make contact if it does.

Fuses also should be standardized. It is perhaps going rather far to hope for it, but the ideal would be a standard system of fuses and fuse boxes so designed that the householder could not insert a fuse of a higher or lower capacity than that for which the board and circuit have been installed.

While there is need to simplify and cheapen the cost of wiring as much as possible to help the would-be consumer to come on to the mains, I must take this opportunity of drawing attention to the deplorable quality of many of the electrical fittings that are at present on the market and are being used in practice by probably the majority of wiring contractors, owing to the stress of competition. Those fittings form only a small percentage of the total cost of a complete installation, and even an addition of 50 per cent to the price would not appreciably affect the aggregate, so that there is no economic excuse for either their manufacture or their use. What sort of quality or service can one expect, having regard to present costs, from a lampholder complete with cord-grip and shade carrier, selling to the trade at 6½d. each, from a wall plug and socket costing 1s. 4½d., or from a tumbler switch at 1s. ? I have looked over samples of fittings taken from a stock heap and bought in the ordinary way (all these are of British manufacture) and I find the following obvious faults :

Lampholders.—Brass casing parts much too light, weighing 1 oz. in all, as compared with 2½ oz. a few years ago. Material too thin to allow of a full thread to shade ring. Contact screws too short, so that they bottom on the head when the point is 1/32 inch from the wall of the hole. Travel of contact plungers varies from 1/32 inch to 3/32 inch. Internal diameter of socket varies by 1/32 inch between one make and another, and cord-grips drilled too small for standard flexible.

Switch lampholder.—The key type should be prohibited, as its use involves severe bending of the flexible cable.

In the Pressel type, I found the wooden cover only engaged one thread, as did the cord-grip socket before the insertion of any flexible cable. The brass contact strips were left black from the annealing. If the push bar were pressed over only 1/16 inch short of its full stroke, no contact was made.

Ceiling rose.—Porcelain cover only engaged for three-quarters of a thread, although three threads were provided. The weight is taken off the terminals by passing the flexible cord through holes in a bridge, these holes having absolutely sharp edges.

The contact plates are so thin that terminal screws only engage by one thread. Terminal barrels were badly fixed to contact plates. Caps and bases are not interchangeable.

Wall plug.—No cord-grip was provided. The fastening of the fibre plate by screws into the porcelain top is most unsatisfactory. Plug and base cover are often made of wood, and this for a fitting that is perhaps more likely to give rise to heating than any other.

No attempt has been made to take off the burrs, even at contacts. The plugs were out of round, due to a wide saw cut, and the permanent compression of the soft brass. The diameter of the plugs was appreciably less than that of the sockets, so that contact results only from the accident that the plugs have not been set on the same centres as the sockets.

Adapter.—This was not provided with a cord-grip, the terminal barrels were only 7/32 inch diameter, and the holes in them for the wires were full of burrs. The thread of the wooden cover was "drunk" and badly chipped, and it was only screwed into position at the third attempt.

Tumbler switch.—This was perhaps the most satisfactory of all, but here the brass cap was much too light, the threaded portion very apt to break away and, in any case in the samples examined, it frequently engaged by only one thread. The contacts were of soft copper and the spring was of poor quality.

I have, I think, said enough to show that serious attention needs to be paid to this matter, and I suggest that it is to the interest of the supply authority to see that none but reliable fittings are used on their circuits, as nothing gets electric lighting so bad a name as the small annoyances the user of electricity is subject to at the present time owing to petty troubles that should not occur.

I am sure that an appreciable revenue is at present lost because of minor faults in fittings, flexibles and so on, and I seriously suggest that it would pay, both directly through the meter readings and indirectly in increased satisfaction to the consumer, if the authority would send a sufficiently trained official periodically to visit each consumer.

Such a man should call twice a year as a minimum ; he would inspect the whole of the installation and see that it was in working order, carry a small bag of tools and do small repairs such as renewal of flexibles, tightening of terminals, etc., then and there. He would also advise as to the candle-power and disposition of lamps if dissatisfaction were expressed, and last, but not least, he could canvass for orders for new business by drawing the householder's attention to the advantages of electric irons, kettles and cooking or other apparatus, with which the consumer did not happen to be provided. Such a representative could be a woman, perhaps with advantage, seeing that calls would be made mostly when only the lady of the house was at home.

A charge could be made for such time as was occupied in repairs, but otherwise the cost would belong to the

supply authority, who would recoup themselves by the added business done or by a small addition to the present charge per unit, which would without doubt be readily paid in consideration of the improved service.

Still another point to which I should like to draw attention is the need for greater care in the earthing of appliances such as kettles, irons, and cooking appliances. Theoretically we are all agreed on the need for it, but in practice it is nobody's job to see that the householder is protected against dangerous shock. The Home Office insists on rigorous earthing for these appliances if used in a factory, and yet if one asks for a three-way plug or for a three-wire flexible the average contractor looks at one in astonishment and pooh-poohs the need for earthing. The last report of the Chief Electrical Engineer to the Home Office mentions that during the last 12 months 18 fatal cases occurred in factories (in spite of their precautions from shock) with alternating current at low pressures, that is, not exceeding 250 volts. Under these circumstances, it is disturbing to think of our wives and daughters, not to mention servants, running the risk of similar shocks because of the absence of elementary precautions.

From the tenor of the last part of my remarks one might think that I was desirous of increasing the cost of wiring rather than of reducing it, but reasonable freedom from risk to life is essential, and money spent in effecting this can be saved many times over by simplification of the wiring itself, and by cutting out all the fads that have grown up around it.

The business of electricity supply is unlike most other trades, in that once having obtained a customer he is almost always a customer for all time, and there is consequently a tendency for the management (being human) to rest on their oars once the undertaking has arrived at a certain profit-earning stage. It is realized in the case of many supply company undertakings that further extension of the business cannot well result in higher dividends without an outcry from the consumers, and in the case of municipalities that the business being worked as it is at cost price in the interests of the community, only additional worry can result from increased turnover, and that in making the supply available to every ratepayer who cares to take advantage of it, all that is really necessary has been done. Fortunately, in both cases man's ambition and the enthusiasm of the manager for what he has to sell prevent complete stagnation.

There are authorities, and they are by no means confined to municipal ones, who presume on the monopoly they have and take advantage of their position to impose irritating restrictions upon the consumer. I know of one company in London which makes a minimum charge of 10s. 6d. for re-connection on a change of tenancy, and of 3s. before a transfer is made from one consumer to another, also 3s. for the re-reading of a meter if there is any question as to the accuracy of the bill. This seems to me the equivalent of a tradesman insisting on the payment of an initial charge before he will consent to do business with his customer, and to his increasing his bill if the accuracy of his scales is questioned. Obviously such charges as these are most irritating, and if the company in question is so poor that it must have additional revenue, I suggest that it would be more diplomatic to increase slightly their charges per unit. The consumer would pay much more readily in this form.

There would seem to be urgent need for increased support to the Electrical Development Association. Everyone seems to be agreed that it is doing good work in "boosting" the use of electricity, but the funds at its disposal are obviously inadequate for the purpose.

There is yet plenty of opportunity for us to reap the fruits of enterprise. It is doubtful if, on the average, more than 20 per cent of the private houses are yet wired for electric light, so that in this direction we have still before us an amount of business aggregating about four times all that we have done up to date. Probably it will never be possible to have every house on the supply mains, but even if in the next few years we only succeed in getting the proportion that The Hague now has, viz. 40 000 wired houses out of a total 50 000, there is a very considerable boom ahead of us.

In conclusion, I hope that nothing I have said will be taken to be in any way a reflection upon the supply manager or the wiring contractor. Both these classes have generally shown much enterprise, and we have none of us the least reason to be dissatisfied with the progress made in electricity supply, especially during the last few years. There remains, however, much more to be done, and I do urge that if only in the interest of trade generally, supply authorities should now review the whole position without prejudice in favour of hampering customs that have grown up round the business, solely, I believe, because of the parliamentary terms under which the various franchises were granted. They should also see whether they cannot so modify the conditions of supply as to secure immediately a large proportion of the additional business that undoubtedly remains to be done.

SHEFFIELD SUB-CENTRE: CHAIRMAN'S ADDRESS

By S. E. Fedden, Member.

(Abstract *of Address delivered at* Sheffield, 23*rd November*, 1921.)

I have had some difficulty in deciding upon a subject upon which to address you to-night. My final choice, however, "What the electricity supply industry did during the war, and what the war did for the electricity supply industry," is one of which I can claim some knowledge.

I think that few of us here to-night had, in that fateful month of August 1914, the remotest conception of the industrial boom which was so soon to follow. The manufacture of munitions became the order of the day, and firms which had probably never seen a shell or a gun, converted their works into miniature arsenals and turned out their wares to their utmost capacity. Then came the demand for everything under the heading of engineering, until every industry in the country became more or less a part of the huge industrial machine created by the war.

Where was the power to be obtained for driving all the new machinery that was pressed into service? This was the problem that very quickly presented itself to the responsible Government Departments, and an inventory of the total capacity of the generating plant available was prepared by them. The undertakings of all the principal industrial centres were soon fully loaded up and, at the request of the Government, took the risk of running their total plant to its full rated capacity without any margin of spare plant until such time as extensions were completed and additional plant could be procured. It bears eloquent testimony to the excellence of British manufactures that, notwithstanding these onerous conditions, there were very few interruptions of a serious nature due to breakdowns of electrical generating machinery.

There can be no question that electricity as a motive power was given its chance during the war; every new factory of which I have any knowledge that was erected for war work was driven by electricity, generally from the public supply where it was available, and only in cases where new factories were remote from public supply mains were private power plants installed.

The following figures serve to indicate the great strides taken by electrical supply undertakings in the period 1914 to 1921:—

	1914	1921
Number of undertakings .	594	642
Plant capacity in kW ..	1 119 617	2 546 000
Output in kWh sold ..	1 316 millions	3 085 millions
Capital expenditure ..	£66 547 126	£92 831 420
Total revenue	£9 408 119	£24 268 482

Only a small percentage of the increase of 1 326 000 kW in plant capacity represents new plant ordered since the conclusion of hostilities in November 1918, so that practically the whole of the additional plant capacity may be said to have been installed for the production of electricity for war requirements, and this endorses the statement made by the Director of Electric Power Supply of the Ministry of Munitions: that "The war definitely established the pre-eminence of electricity as *the* motive power for industry."

The above figures showing the growth of electricity supply generally in this country are indeed of a remarkable character, but I think it will be agreed that the growth of the Sheffield undertaking, which is shown by the following table and which is far in excess of the average for the country, cannot be described as anything less than phenomenal. As regards the output, on account of the unfortunate slump in trade the units sold last year fell far below the figure that would otherwise have been reached, and in 1917 they were 30 millions in excess of those sold last year.

Figures for Sheffield Electric Supply Undertaking.

	March, 1914	March, 1921	Increase
			%
Plant capacity ..	23 225 kW	93 000 kW	300
Maximum demand ..	14 934 kW	66 463 kW	271
Units sold	26·5 millions	141·3 millions	433
Number of consumers	6 225	12 428	100
Total connections ..	41 109 kW	189 233 kW	360
Capital expenditure ..	£1 222 648	£3 440 431	181
Total revenue ..	£149 891	£1 082 025	621

Let us now consider for a few minutes what the war has done for the electricity supply industry. Very early in the war it was revealed that the supply of electricity was essentially a key industry and that practically every industrial process was dependent upon it in some form or other. For the purpose of obtaining the greatest efficiency from existing plants, and exercising economy in coal consumption, the Board of Trade circularized all undertakings in May 1916, to consider carefully the question of interlinking and joint working, and undertook to give immediate attention to any application for the necessary powers to put such arrangements into operation. The Board further offered their services in removing any difficulties in the way of securing agreements of all interesting parties.

Various groups of undertakings took the matter up energetically and formed engineering committees to investigate the linking-up problem. As a result a number of well-considered comprehensive reports on the subject were prepared, although up to the present none of the larger interlinking schemes has been put into operation in its entirety, probably in view of the uncertainty of what will happen as a result of the 1919 Electricity Act. A considerable number of linking-up schemes are, however, working to-day, and these will afford practical experience for future investigation. In addition, it is quite possible that the recommendations made by these linking-up committees may play a large part in the reform of electricity supply over extended areas, which is now engaging the close attention of the Electricity Commissioners.

The next step taken in connection with the re-organization or re-construction of the industry was the appointment in June 1916 of the Coal Conservation Sub-Committee. Many of the conclusions arrived at by the Committee were already well-known to station engineers long before the issue of the Interim Report in 1917, and great efforts had been made in the past by engineering bodies, including this Institution, to procure greater freedom from the retarding influence of the Electric Lighting Acts of 1882 and 1888.

The Report was not accepted by any means with unanimity, and received much criticism, although the suggested appointment of Electricity Commissioners with expert knowledge of the industry and full powers to deal with the electricity supply situation throughout the country was welcomed in all directions as a necessity for the proper development of the industry. This Report was followed by another from a Committee appointed by the Board of Trade, the Electric Power Supply Committee, which was called into being to consider and report what steps should be taken to ensure that there shall be an adequate and economical supply of electric power for all classes of consumers, particularly industries which depend upon a cheap supply of power for their development. The Committee's investigations revealed the same unsuitable conditions which had presented themselves to the Coal Conservation Sub-Committee.

The Reports were sufficient to convince the Government that something ought to be done to assist the development of the industry, and the principal recommendations were embodied in due course in the new Electricity (Supply) Bill. The draft Bill when published met with a very hostile reception, due chiefly to a few contentious clauses relating to the formation of District Electricity Boards and the compulsory handing over of all generating stations and main transmission lines to these Boards, and to the financial clauses. By the time the Bill reached the House of Lords the protests had become so vigorous that the Government had to choose between dropping the whole Bill or withdrawing the objectionable features. The latter course was adopted and, as a result, the Electricity (Supply) Act, 1919, came into being. This is undoubtedly one of the most satisfactory pieces of legislation since the industry was founded, and, for the first time in its history, undertakings are able to submit their proposals to a Committee of experts in the knowledge that they will be considered upon their merits and that decisions will be made without reference to political considerations.

Quite apart from the *pièce de résistance* of the Act, by which I refer to the sections dealing with the formation of the country into electrical areas, the Commissioners are given powers to sanction the performance of various works which were impossible under the previous Acts.

Early in 1920 a further Electricity (Supply) Bill was presented by the Government; it was practically a reiteration of the clauses which had been struck out of the former Bill, and towards the end of the year it was withdrawn, the Minister in charge promising to introduce a smaller measure which it was expected would be generally approved. This promise was fulfilled and the latest Bill does not contain the contentious clauses which have been a feature of all its forerunners. The Bill was, however, not pushed forward and was finally withdrawn last August.

With such a plethora of Government Inquiries, Reports and Bills on the subject of electricity supply extending over a period of something like 6 years, it will surely be impossible for the industry to be forgotten in the future and allowed to struggle along in spite of the obstacles which former legislature saw fit to place in the way of development. Such a condition, I feel sure, cannot again return now that the Government Departments controlling the industry are under the direction of qualified officials who are familiar with, and experienced in, the practical side of public electricity supply.

The war has therefore been the means of bringing the previous defects into prominence, thereby causing a concentration of effort in high quarters to devise means for exterminating such defects, and in 7 years has accomplished more towards building up the industry than the most sanguine supply engineer ever dreamt of. There always has been a great future for electricity supply, given proper encouragement, and the attainment of the ideals for which all electrical engineers have been striving has been brought infinitely nearer as a result of the efforts that have been expended during the short period which I have so briefly reviewed.

THE DESIGN OF ARMATURE WINDINGS FOR DIRECT-CURRENT DYNAMO-ELECTRIC MACHINERY.

By H. E. Dance, Student.

(Abstract *of paper read before the* Liverpool Students' Section, 17*th February*, 1921.)

Summary.

Section 1 deals with the electrical design of open-circuit windings on the high-voltage machines used in connection with arc lamps in series; and the Brush open-circuit generators. The small hand-driven generators used in insulation-testing sets are also mentioned. Attention is drawn to the fact that interpoles were not introduced before these designs were superseded. Closed-circuit windings are dealt with, and it is pointed out that ring windings have gone out of use except for the special cases mentioned. The drum winding is then discussed.

Section 2 deals with mechanical design.

Section 3 treats of the effect of the number and dimensions of the core slots in relation to various aspects of the design. Attention is drawn to the effect on commutation of slots containing coils of various numbers of turns. Mention is made of the points to be noted in selecting the number of slots and coils.

Section 4 deals with limiting factors in design.

Section 5 shows how the ratio of diameter to length of armature for the minimum inductance of coil is deduced, and draws attention to the loss due to inductance.

Section 6 treats of the effect of coil pitch on both commutation and armature reaction. General formulæ are given for the period of commutation.

Section 7 discusses special connections and their use in increasing the number of commutator bars, and draws attention to the factors limiting the output of direct-current machines.

Section 8 deals with the factors affecting the electrical balancing of windings.

Section 9 discusses windings for special purposes.

Introduction.

In discussing the subject of direct-current armature windings, the whole electrical design of the machine is involved. For this reason, one or two items dealt with in this paper, while not strictly covered by the title, have been included.

As regards mechanical design, it may be said that the slotted-drum barrel-wound armature holds the field for use in commercial machines at standard direct-current voltages; the older types are mentioned, however, together with the early electrical designs.

(1) Electrical Design (exclusive of High-Speed Turbo Sets).

When studying armature windings, the first type brought before the student is the single-coil armature with a 2-section commutator. This, of course, has no practical application, but a slight modification of it was adopted by the British Thomson-Houston Co. for their direct-current machines for running arc lamps, the output being 6 amperes at 3 000 volts (maximum). It is, in effect, a three-phase winding connected to a 3-segment commutator. A consideration of this type will show that the contact between brush and commutator segment will be broken when the coil is carrying quite a considerable current, and indeed the sparking was very pronounced on these machines, considering the low value of the current carried.

Another form of open-circuit winding is that constructed by the Brush Electrical Engineering Co. It consists of a number of single-coil windings connected in series. A serious disadvantage of this type is, that in order to ensure that one active coil shall not be short-circuited by the commutator sector of another coil undergoing commutation, the distance between sectors must be appreciably greater than the width of the brush. As this is directly opposed to favourable commutation, sparking occurs.

Although both these types have become obsolete they are interesting from the historical point of view, especially the latter which, slightly modified, is utilized in the hand-operated, high-voltage direct-current generators for insulation-testing sets, for which purpose they are commonly wound for 500 or 1 000 volts.

In considering direct-current windings it should be remembered that these were in use before the advent of the carbon brush and the interpole.

There are only two general types of closed-circuit windings, viz. the ring winding, which has, however, gone out of use except for certain single-unit auto-converters and balancers, and the drum-wound armature. This form is well known and does not call for further remark at present.

(2) Mechanical Design.

The ring winding, owing to its inefficiency from both the theoretical and practical points of view, has given place to the almost universally-used barrel winding. This type is used in machines varying in size from 2 h.p. to 3 000 kW; the only difference in the small sizes being that the coils are of wire instead of strip and that bands instead of slot wedges are used on the core.

Strip coils are shown diagrammatically in Figs. 1 (*a*) and 1 (*b*). The single bend can be formed for either lap or wave winding, while coils of two (or more) turns, consisting of strips half the depth of the slot, can be used for lap winding only. For wave winding it is necessary to bring the leads out "top and bottom"

so as to avoid awkward and dangerous bends over the commutator end-winding.

Fig. 1 (*b*) shows coils arranged for this purpose. The cross-over, being taken at the knuckle, requires fairly heavy insulation and makes the back end somewhat bulky.

Fig. 2 shows an alternative method of obtaining the same results without a cross-over. Although this is satisfactory for small machines, it has the disadvantages of splitting the winding into twice as many layers as there are turns per coil, and as a result the space factor is decreased; but this form on the whole gives a very compact winding.

The "short" coil, besides possessing the advantage of a short overhang, gives a very solid end, the straight parts being formed to an involute curve and made solid with a good band. No further support in the way of core end-plate or coil plates is necessary.

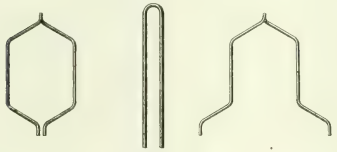

Fig. 1 (*a*).

Another type, the involute, only shows an advantage in coils consisting of single turn of strip, this being easy to form and fairly rigid. Multi-turn coils are, however, difficult to manufacture and tend to become bulky at the bottom of the involute. Further, the cooling area of this winding is small compared with that of a barrel winding of similar weight, and the overhang of the coils does not assist ventilation. This type is sometimes used on turbo-generators when connections are made between the back-end knuckle and intermediate commutator bars, as the knuckle is brought down to a convenient point for connecting without awkward turns or bends.

Fig. 1 (*b*).

The mush winding is used only on small armatures, the coils being wound with fairly flexible wire.

(3) Slots.

Although there are many advantages to be gained by the use of wide slots, such as higher space-factor, wider range of windings for the same core-discs, greater economy in manufacture, etc., the minimum number of slots is strictly limited, and, as the width of slot is usually made equal to the width of tooth at the periphery, the width and depth will also be limited.

The following table represents modern practice in this respect:—

kW at 1 000 r.p.m.	2·5	10	20	30	40	50	75	100	150	200	400–1 000
Slots per pole	5	5·5	7·25	7·8	8·3	8·75	9·4	9·9	10·75	11	12

The above values are about the most economical, trouble being experienced with commutation if these minimum limits are passed. When we consider the effect of winding on commutation, we see that it is often convenient to make the coil pitch one slot less than the diametral pitch. At the same time it must embrace the pole arc and the effective flux fringe as much as possible, so that the slot pitch should not be greater than the width of the neutral zone between the poles. Further, in interpole machines the slot pitch should not be so large as to necessitate a very wide interpole, as this will increase the leakage flux, both round the armature conductors and from the interpole to the main pole. For the same reason, there should not be less than $3\frac{1}{2}$ slots between the main poles.

It is important to note that, when an armature is designed with a large number of coil sides per slot, each coil will not be in the same position relative to the field when undergoing commutation. For instance, some coils will be either over-commutated or under-commutated, in which case the brushes will have to ensure sparkless running. In certain instances the difference in reactance volts might be too great for carbon brushes to deal with.

When calculating windings for standard cores, especially in small machines, it is sometimes necessary to use coils containing different numbers of turns; for instance, three coils with two turns and two coils with one turn may be grouped together in one slot. The brushes would then have to effect about 33 per cent of the commutation, even if interpoles were fitted. If these turns are now re-arranged so that the one-turn coils are in the leading side of the slot they will undergo commutation while passing through a weak field, while the two-turn coils will be in a somewhat stronger field when they come under the influence of the brushes, which are, of course, adjusted to give sparkless commutation. This will also hold good in the case of an interpole machine, the one-turn coils not being under the full influence of the interpoles during commutation. This arrangement cannot be applied to reversible machines.

The weight of copper on a machine with comparatively narrow cores can be reduced by making the slots as deep as possible. This will naturally shorten the overhang, and, although the inductance of the slot portion of the coil will be somewhat increased, that due to the free part will be decreased on account

of the reduced length. Unfortunately, the majority of short cores occur on standard machines which have been cut down in length, so that it is necessary, from the point of view of economy, to use standard discs.

Skewed slots are adopted for one, or both, of two reasons, viz. to increase the time during which the coil is under the influence of the interpole, and to reduce humming (the tooth enters the flux more gradually, although in my experience the advantage gained is not always as great as might be expected).

The number of slots for a standard disc must be such that, when taking 4, 6, 8 or 10 coil-sides per slot, they can be connected up so as to leave the minimum number of dummy coils. Six-circuit wave windings are not used to a great extent on standard machines, but if constant at about 5/32 inch. The permissible voltage per commutator segment depends, however, on the type of field winding adopted. For shunt windings the value should not exceed 15 volts per segment. For compound machines this value may be increased slightly, while for those fitted with interpoles it may be increased to 25 volts. For machines fitted with compensating windings the value may be increased to 30 volts, on account of the more even distribution of field and consequent minimized danger of "flashing over."

The adjustment of turns is limited in the minimum by the single turn (except in the special windings referred to later) and in the maximum by the reactance voltage and, as before, the voltage per segment. From

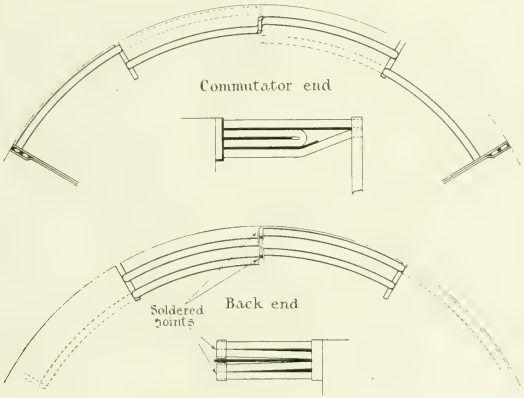

FIG. 2.

a certain number of slots will fulfil this condition, in addition to the usual requirements, that number should be chosen.

(4) LIMITING FACTORS IN DESIGN.

The first condition that an armature must fulfil is that, when rotated at the required speed, it will generate the necessary electromotive force. When designing a new frame this can always be arranged within the limits of standard voltages, and the armature in this case is proportioned to the requirements. In specifying a winding for a standard frame, however, the field strength may have to be reduced. If sufficient latitude is not offered by this, the number of coils and turns per coil must be adjusted. The number of coils is limited, as regards the minimum, by the permissible voltage per commutator bar, and, as regards the maximum, by the minimum width of commutator segment. The last is a purely mechanical limit and remains these considerations it will be seen that a larger range in the selection of windings for standard frames may be obtained by keeping the reactance voltage as low as possible, and the width of slot as large as possible consistent with the first condition.

(5) REACTANCE VOLTAGE AND COMMUTATING PERIOD.

The reactance voltage of a winding is dependent on three factors, viz. the inductance of the coils under commutation, the time of commutation, and the current commutated. The last factor is determined by the number of circuits, and cannot be adjusted to the same extent as the first two. By keeping the value of the first item as small, and the second as large, as possible, the cost of the machine will be reduced to some extent. With a low reactance voltage, interpoles are reduced or even eliminated, or if they are used at their maximum value the weight of the commutator copper is reduced by the use of soft brushes.

The reduction in reactance voltage can be attained by correctly proportioning the diameter of armature, D, to its length, l. An approximate value for this ratio is given in Appendix 2 and is approximately $2p$, where p is the number of pairs of poles. This ratio may be either increased or decreased by 50 per cent without causing a serious (say 10 per cent) increase in the reactance voltage, but is rather high from the commercial point of view and is only approached in practice when two or three values of D^2l are obtained from frames of the same diameter. The "short" cores always behave best from the point of view of commutation. In non-interpole machines having pure brush commutation the number of turns per coil should be kept as small as possible so that the commutation loss ($\frac{1}{2}LI_a^2 \times 2p \times C \times n$ joules per min.) is a minimum; in interpole machines and in machines of moderate size this loss may be neglected, as in the first case the energy is dissipated by the coil acting as a motor, and in the second case L may be neglected. The total loss very rarely exceeds 1 per cent, even in small machines at high speeds, the more usual value being below 0·25 per cent, reaching a maximum in reversible non-interpole machines.

(6) Coil Pitch.

If the coils are wound on a diametral pitch the top and bottom coils in one slot undergo commutation at the same time; thus the flux produced by the currents in both coils will be linked with each. If the winding pitch were made one slot less than this, each coil would be linked with its own flux plus a small flux due to the currents in both coils and embracing two slots. The reduction in inductance will usually be from 25 to 30 per cent, a further reduction by one slot only effecting a reduction of from 33 to 50 per cent. In any case the coil should embrace one pole arc, plus the effective fringe of flux. In interpole machines, unless the number of slots per pole is large, the coil pitch should be kept as nearly diametrical as is consistent with the above considerations, or else the interpole will be excessively wide. Average values of coil pitch met with in practice vary from 89 to 93 per cent of the pole pitch.

It should be noted that in non-interpole machines the demagnetizing effect of a short-pitch winding is not so great as that of one wound diametrically. This is due to the fact that the coil under commutation is not in a neutral field but lies in the flux fringe of the main pole, so that the commutating E.M.F. is the difference of two opposing E.M.F.'s of fairly high value, not, as in the case of the diametral winding, the sum of two small E.M.F.'s. For this reason a much smaller brush displacement is required to effect good commutation and, consequently, there are fewer demagnetizing ampere-turns on the armature, but it must also be noted that a very much finer adjustment of the brushes is essential. Conversely, sparking is produced by a very small change of load. As remarked before, interpole machines should be wound diametrically in order to obtain good commutation and narrow interpoles, and the demagnetizing effect is small, as very little or no lead is needed. Indeed, in small machines with hard carbon brushes it is possible to obtain a compounding effect due: (*a*) to the interpole flux increasing with the load, and (*b*) to the magnetizing effect of the armature obtained by giving the brushes a backward instead of a forward displacement.

In the case of a lap winding the time of commutation is equal to

$$\frac{\text{(width of brush)} - \text{(width of mica)}}{\text{velocity of commutator}} \quad \text{or} \quad \frac{b - m}{v}$$

In addition, the coils will be short-circuited individually by the brushes.

The time of commutation of a wave winding with only two brushes will be similar to that of the lap winding, but p coils in series instead of one will be short-circuited. The use of two brushes on a multipolar wave-wound machine is limited to very small outputs for this reason, even in machines fitted with interpoles.

When one brush-arm per pole is fitted, each coil undergoes commutation individually, but through two sets of brushes instead of one as before. It is true that sets of p coils in series are partly commutated through each brush, but the commutation of any coil commences and finishes individually. The parallel coils enter and leave the circuit in a shorter period.

In the case of multiple windings the commutating periods will be:

$$t_l = \frac{b - m - S_p\left(\frac{a}{p} - 1\right)}{v}$$

$$t_w = \frac{b + S_c - \left(\frac{aS_p}{p}\right)}{v}$$

where the symbols have the meanings assigned to them in Appendix 1.

(7) Special Windings.

The commutation of currents in lap windings can be improved if special connections to intermediate commutator bars are employed, as shown in Fig. 3,* in which case the inductance is halved. Fig. 4 shows the application to a double lap winding.† In this case, in addition to the inductance being halved, the time of commutation is increased. It should be noted that the inductance will be a minimum when "back to front" connectors spaced 180 electrical degrees apart are brought through the same opening in the core, the currents in each practically neutralizing each other, otherwise the inductance of these connectors will be greater than that of the coil itself. These leads are, however, difficult to support and, as connections 180 degrees apart are placed in proximity, they must be heavily insulated. Thus, although the conductors can be run at a high current-density, they take up a considerable portion of the axial ventilating ducts in the core. Fig. 5 indicates this method applied by connecting corresponding equalizers,‡ so that the total

* B.T.H. patent No. 24 992.

† R. Pohl, "The Development of Turbo-Generators," *Journal I.E.E.*, 1908, vol. 40, p. 239.

‡ *Journal I.E.E.*, 1907, vol. 39, p. 600. Patent No. 10 861.

potential difference of the machine is evenly distributed over the commutator segments.

This type has been utilized on a 40-volt, 1 800-ampere generator running at 540 r.p.m. The reactance voltage before the equalizers were cross-connected was approximately 2 volts: when the connections were fitted the machine ran sparklessly with copper brushes in the neutral position at full load. It may be remarked that 2 volts is considered to be the limit for carbon-brush commutation when the brushes are in the neutral position.*

Another method (see Fig. 6) has been applied by the British Westinghouse Electric Manufacturing Co.† This requires deeper slots at the commutator end of the core, unless the designer is willing to run the conductor at a higher density at this end. As the

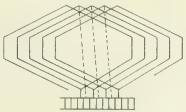

FIG. 3.

intermediate connections are in circuit for only a comparatively short time they may be run at a fairly high density without excessive heating. This design permits a much greater division of the coils as, by splitting up the core into sections, the number of commutator bars can be increased until the mechanical limit is reached. The inductances of the circuits between adjacent segments may not be exactly equal, but this

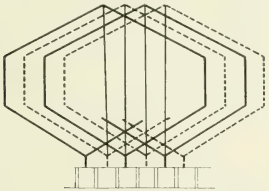

FIG. 4.

may be rectified by splitting the interpoles up into sections corresponding to those of the core, and, in addition to the main coil round the whole interpole, each section would be fitted with a supplementary coil when necessary, which could be adjusted as required. The mechanical construction of this type is very much more simple than that of the preceding type.

Various schemes in which the connectors from the coils to the commutator risers are brought back over the core have been proposed from time to time. The difference in E.M.F.'s induced in these connectors produces the necessary E.M.F. for commutation. None of them, however, has been found to be really practicable, due, probably, to the fact that they are difficult to adjust when wound; also, there will be a definite limit to the effective E.M.F., unless multi-turn coils are introduced, a scheme which would not be very favourably received by the manufacturers. Moreover, if more than 2 coil sides were placed in each slot the difference in the induced E.M.F.'s would not be constant, while if only 2 coil sides per slot were used the machine would be unduly expensive.

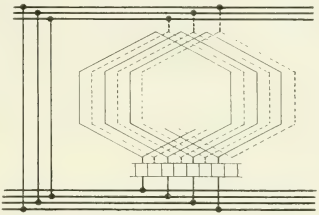

FIG. 5.

Limits of direct-current windings.—The potential difference between two adjacent commutator bars is a quantity which must be carefully noted during the design of windings for large machines. This value (the limits for which have been given previously), together with the peripheral speed and the ampere-conductors per unit length of armature periphery, forms the limit to the output of direct-current machines (see Appendix 3). The special windings for the reduction of reactance volts, previously mentioned, are also applied with the object of increasing the output by introducing more segments and so reducing the potential difference between adjacent commutator segments. In fact, the limiting values of all three factors have been reached in direct-coupled turbo-generators with ordinary windings. The only means of further increasing the output is to split up the coils in the manner indicated. An alternative arrangement which, however, is not so flexible in adjustment as that shown in Fig. 6 is to ring-wind the armature and thus halve the voltage per commutator bar.

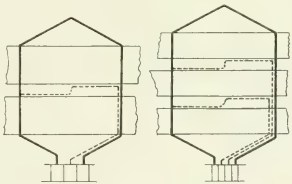

FIG. 6.

This value (E_s) also limits the application of wave-

* *Journal I.E.E.*, 1907, vol. 39, p. 600.
† *Ibid.*, 1908, vol. 40, p. 256.

windings to large outputs, since the total number of coils equals the total number of commutator bars, which is 2 × (number of coils in series), a quantity independent of the number of poles. As it is not practicable to collect more than from 500 to 1 000 amperes at each brush-arm, a minimum value is placed on the number of poles, which tends to become excessively high for wave windings as the output increases. On the other hand, the value of E_s is not affected by the number of poles in a lap-wound machine, provided the peripheral speed, length of core, and the number of turns per coil are constant. Thus, if the limiting output of a certain theoretical design is reached, we can introduce a few more poles, increase the diameter, and decrease the speed of rotation in proportion. We see from this that as the required speed decreases, the limiting output for which we may design a machine increases, the only limits in this direction being first cost, floor-space, and mechanical design.

These remarks apply only when single-turn windings are being compared.

(8) Balanced Windings.

To avoid all possibility of circulating currents, the winding and also the magnetic field must be absolutely symmetrical. The magnetic field depends on good workmanship and homogeneous castings or sheet; while the first condition requires that the number of slots must be divisible by half the number of parallel circuits and by the number of pairs of poles. When the latter condition does not hold, or when—as sometimes occurs in small wave-wound armatures—odd-turn coils are used, circulating currents may be set up. Usually, however, the frequency of the electromotive force producing these circulating currents is so high that their value is small and for practical purposes they may be neglected. Very low-speed machines are, however, only rarely met with, the majority of cases of circulating currents being found in the lap winding. In those cases the currents are continuous through the brushes or other paths provided, and are not dependent on the speed.

The usual method of dealing with unbalanced circuits is to fit so-called "equalizers," after taking all precautions to see that the fluxes are as nearly as possible equal.

It should be noted, however, that although these connections balance the currents in the collector gear, they actually increase the circulating currents in the winding, since a path of lower resistance is provided.

Lap windings are more liable to circulating currents in machines fitted with interpoles in the usual position than in those not so fitted. This is due to the fact that the number of demagnetizing turns on the armature is much greater in non-interpole machines than in those fitted with them, owing to the large lead required in the first case. This effect can be brought about in interpole machines by displacing the interpoles so that they are fitted on one side of the neutral line. By this means a demagnetizing belt of armature ampere-turns is produced, although it may be necessary to increase the interpolar arc to some extent to accommodate the displaced interpole.

(9) Windings for Special Purposes.

When it is required to run a machine at constant torque on a large range of speed, we must either employ series control, install two machines for series-parallel control, or wind one machine with a double armature winding for use in the same way. These windings do not differ greatly from the standard construction, so far as mechanical design is concerned. It is interesting to note, however, that if both sets of brushes are given the same amount of lead, the flux due to both coils will change at the same instant. Better results are obtained if one lead is made somewhat greater than the other. In the case of machines fitted with interpoles this difference in position—the brushes being placed on opposite sides of the neutral line—necessitates the use of wider interpoles.

Similar windings are sometimes used for converting from one voltage to another. Their field of application is not wide, however, owing to the difficulty of commutation in large sizes, and to the fact that the voltage ratio is constant unless one winding is extended to a short auxiliary core, the flux for exciting which is provided by a separate set of poles. This type of winding should always be on a diametral pitch.

It should be noted that it is impossible to use interpoles in these machines, as one winding requires these to be of one polarity and the other of the opposite polarity. On the other hand, the armature reactions of each winding are practically neutralized by the other, and, as their currents flow in opposite directions, the reactance voltages of the coils will be considerably reduced. However, when the machine reaches such a size that the brushes must be given a lead to secure good commutation, the fact that the coils under these circumstances are commutated at different periods will still further increase the reactance voltage.

In conclusion, the author wishes to thank the British Thomson-Houston Co., Ltd., the English Electric Co., Ltd., the Metropolitan-Vickers Electric Co., Ltd., and Messrs. H. T. Boothroyd, Ltd., for supplying information which has been utilized in this paper.

APPENDIX I.

List of Symbols used in the Paper.

a Number of pairs of parallel circuits in armature.
ac Ampere-conductors per unit length of armature periphery.
b Width of brush.
C Number of coils.
D Diameter of armature, or diameter of round wire.
d_c Diameter of commutator.
E Terminal potential difference.
E_s Potential difference between adjacent commutator segments.
I Total current, in amperes.
I_a Current per armature conductor, in amperes.
K, K_1, K_2, etc. Constants.
l Length of armature core.
l_e Embedded length of conductor.

l_f Free length of conductor.
L Inductance of armature coil.
m Number of coils short-circuited by brush, or thickness of mica.
n Speed of rotation, in r.p.m.
p Number of pairs of poles.
R_v Reactance volts.
r Ratio D/l.
S_c Width of commutator segment.
S_p Pitch of commutator segments.
T_c Number of turns per coil.
t Time of commutation.
t_w Time of commutation of wave winding.
t_l Time of commutation of lap winding.
v Peripheral speed of armature or commutator.

APPENDIX 2.

Assuming that the E.M.F., output, speed, width of commutator segment, width of brush, and type of winding remain the same, that $D = Kd_c$, and that I_a and m are constant, we have :—

$$\text{Total flux} = K_1 Dl\ ;$$

$$\text{Total number of turns required} = \frac{K_2}{Dl}$$

and the maximum number of commutator bars $= K_3 D$.

Therefore the number of turns per coil $= \dfrac{K_2}{DlK_3 D}$

$= \dfrac{K_4}{D^2 l}$ = constant, since the output is constant.

Also, the time of commutation $= \dfrac{K_5}{D}$,

$$l_e = 2l, \quad \text{and} \quad l_f = \frac{9 \cdot 42D}{2p},$$

as the length of overhang is approximately 1·5 times the coil arc.

The formula for R_v given by Hobart * may be taken as approximating to this, i.e.

$$\frac{16(l_e + 0 \cdot 1 l_f) I_a T_c^2 m}{10^8 t} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

* "Elementary Principles of Continuous-Current Dynamo Design," p. 108.

From the above considerations this may be written :

$$K_6\left(2l + \frac{0 \cdot 942D}{2p}\right) \Big/ \frac{1}{D} \quad . \quad . \quad . \quad . \quad (2)$$

$$= K_6\left(2Dl + \frac{0 \cdot 942D^2}{2p}\right) \quad . \quad . \quad . \quad . \quad (3)$$

Now $D^2 l = K_7$ and $r = D/l$

therefore $D^2 = \dfrac{K_7}{l} = \dfrac{K_7 r}{D}$

Hence $D = K_7^{1/3} r^{1/3}$

Similarly, $l = \dfrac{K_7^{1/3}}{r^{2/3}}$

Substituting these values in (3) we have :—

$$R_v = K_5\left(\frac{2}{r^{1/3}} + \frac{0 \cdot 942 r^{2/3}}{2p}\right)$$

When R_v is a minimum, $\dfrac{dR_v}{dr} = 0$

that is, $\dfrac{0 \cdot 314}{pr^{1/3}} = \dfrac{2}{3r^{4/3}}$

or $r = 2p$ (approx.)

APPENDIX 3.

Limiting Factors in Direct-Current Design.

Assuming one turn per coil only, we have :—

$$E = \frac{E_s C}{2p}$$

and $I = \dfrac{(ac) \times 3 \cdot 14 Da}{C}$ (where D is the diameter of the armature).

Therefore $EI = E_s \times (ac) \times av\left(\dfrac{1}{2pn}\right)$

From this we see that the limiting factors are :

(1) Voltage per commutator bar ;
(2) Ampere-conductors per unit length of periphery ;
(3) Number of parallel circuits in armature ; and
(4) Peripheral speed.

PROPERTIES AND CHARACTERISTICS OF INSULATING MATERIALS.

By R. T. Fleming, Student.

(Abstract *of paper read before the* North-Western Students' Centre *at* Manchester, *18th January*, 1921.)

Summary.

The subject of insulating materials has been considered in this paper under five main headings, of which four are dealt with in this abstract. The fifth section was chiefly concerned with the properties of well-known forms of moulded insulation, which were considered in more detail in an earlier paper by the present author.

Section 1 here deals with the manufacture and properties of porcelain, and describes the various processes in common use, and their application to transmission and terminal insulators.

Section 2 deals with mica insulation, the physical properties of mica, its use in its natural form as an insulator, and the various fabricated insulators in which it plays an important part.

Section 3 treats of fibrous insulation, including papers and cloths and various insulators made with these materials as a base, such as "Micarta," etc.

Section 4 deals with liquid insulation, including transformer and switch oils and varnishes employed in impregnation and dipping processes in connection with coils, etc., used in electrical apparatus.

(1) Ceramics (including Porcelain).

The main object of this portion of the paper is to give a general outline of the properties of this material.

The term "composite insulating materials" may here be somewhat misleading when used as a classification for substances other than porcelain, because porcelain itself is a composite material, being a compound of several bodies, such as china clay (kaolin), felspar, etc. However, porcelain is usually placed by itself under a heading of "Ceramic Insulating Materials." Glass and lava products may also be included here, although they are of less importance.

Composition.—The chief ingredients of porcelain are felspar, clay, and silica. It is very difficult to obtain any definite data as to the composition of these several ingredients, as it is very subject to variations both chemically and physically. One of the greatest difficulties confronting the manufacturer of porcelain is the uncertainty as to the uniformity of new consignments of the raw materials ; a slight difference in composition may cause some of the finished products to be unsatisfactory.

Manufacture.—The process of porcelain manufacture for electrical purposes is very similar all over the world. A brief description of the English method is given below.

Wet process.—The ingredients are taken from the storage bins and then thoroughly crushed to a fine powder until they can pass through fine lawn woven with 100 to 150 threads to the inch. The materials are then mixed in the correct proportions and water is added ; this is carried out in a tank known as an "agitator" or "blunger," which is mechanically operated and which mixes the various ingredients very effectively. A thick whitish fluid known as "slip," having the consistency of cream, comes from this tank. This is then passed through sieves and very frequently is allowed to flow over a board studded with electro-magnets, in order to remove any iron matter which may be present. When this process is complete the "slip" is pumped into a filter press and squeezed under a pressure of from 4 to 6 atmospheres, thus getting rid of any excess of water. The clay comes from the press in lawns, and is quite soft and plastic. The next process is to pummel the substance on a slab, cut the clay and knead it together and cross and re-cross any semblance of grain in the mass. Following this treatment, which is carried out by hand, the material is placed in a pug-mill. This consists essentially of a helical screw, and works on the principle of a mincing machine. The mill cuts the plastic mass and finally pushes it out in a long slab about a foot square. The porcelain mass is then ready for the potter's wheel.

The time of drying varies with the state of the atmosphere and the number of pieces in the drying racks. When the material is sufficiently dry to handle it is taken to the lathe, where the correct shapes and sizes are cut from it. When the turning is finished the pieces are taken to a second drying room, where they remain until they are in a fit condition to go into the kiln for vitrification, after being examined for flaws.

The pieces of porcelain are placed in "saggers," which are large circular dishes about 18 inches in diameter, and 6 inches high. They are made of some earthenware material having a higher softening point than the porcelain mass. When these saggers are filled with the pieces they are piled on top of each other in the kiln, in the form of columns known as "bungs." When the kiln is filled, the door is bricked up and the temperature gradually raised to from 1 250 to 1 300° C. The heating process takes about three days and a similar length of time is allowed for cooling ; when the furnace is sufficiently cool the door is knocked down and the saggers containing the now vitrified material are removed. This unglazed ware is known as bisque or biscuit ware ; it is electrically and mechanically strong, but the unglazed surface is very apt to attract moisture and dirt. In order to prevent this, the material is glazed. In English porcelain the glaze is applied as a protective coat only, and it in no way enhances the electrical or mechanical strength of the finished product.

The glaze is applied by means of dipping, and consists essentially of the same ingredients as the porcelain, except that it contains a higher percentage of flux. After being dipped the pieces are again placed in a kiln, known as a glazing oven, and the final stage of the manufacture is then complete.

Abroad, the glazing and vitrification of the mass are done at the same time. In this case the glaze plays a part in the final strength of the piece.

Dry process.—In this process the raw materials are in a slightly moist form, resembling damp sawdust and containing from 15 to 25 per cent of moisture. The moist powder is worked to take the desired shape by means of high mechanical pressure in moulds. The pressing of this "dry process" porcelain does not exclude all the air from the mass, hence the finished pieces are rather porous and the resultant dielectric strength is not much greater than that of air. There are many other methods of shaping pieces, the most important being plaster mould work.

Testing.—The testing of porcelain insulators is here considered from the electrical point of view; that is to say, such tests as are often carried out upon samples of the material will not be fully discussed.

The usual tests include the following:

(*a*) Quality tests.
(*b*) Flash-over voltage tests.
(*c*) Puncture tests.
(*d*) Reliability tests.

Preparation of samples for tests.—A general idea of preparing a specimen can be given in the case of one of the commonest forms of terminals, where the piece has a grooved top, the remaining portion being flat. When testing these pieces it is necessary to find the flash-over voltage for the grooved portion. One method is to bind the insulator with copper wire where it would come into contact with the tank, and then to place an electrode on the top. The pressure is then applied until flashing-over takes place. An alternative method is to place a conductor inside the insulator. In this case it is necessary to place the plain portion under oil to prevent a discharge along the bottom path.

The method of preparing the various terminal insulators does not vary greatly from that which has been already described. Tin and lead foil instead of copper wire are sometimes used on the outside. Tests are very seldom carried out on low-grade porcelain, such as that employed for tumbler-switch covers.

The method of preparation in the case of transmission insulators differs very largely from that employed in the case of terminal insulators. When pin-type units are tested they are erected in the same manner as they are mounted on the poles; this also applies to suspension insulators, although these are tested as single units as well as in chains. When a puncture test is undertaken it is necessary to place the specimen under oil.

The value of the flash-over voltage does not entirely depend upon the shape and size of the insulator. The quality of the porcelain itself is a factor in deciding this question. This does not imply that a very small insulator might stand a greater pressure than a large one, but if two specimens of exactly the same shape and dimensions were tested, one of good quality and the other of bad, different values would probably be recorded. The deciding factor in this case could not be the shape, as it is the same for both, and, assuming all other external conditions to be similar, the divergency would be due to the quality of the porcelain. That is to say, the specific inductive capacity or dielectric constant would be the deciding factor in fixing the flash-over pressure.

The greater the specific inductive capacity of the dielectric the lower is the voltage at which flashing-over will take place. It is well known that solid and liquid dielectrics allow the transmission of inductive effects better than air, and the introduction of such a substance into the field produces the same result as a reduction of the air-space.

If D cm is the width of an air-gap and KD cm the width of some other dielectric electrically equivalent to it, then K is the specific inductive capacity, hence it can be seen that insulators identical in shape, but made of materials whose dielectric constants vary, produce the same result as an alteration of the air-space, i.e. the flash-over value alters. The following tables show the variation in flash-over values on exactly similar insulators tested under identical conditions.

Insulator	Flash-over Value	
	Material A	Material B
	kV	kV
No. 1	56·3	59·2
No. 2	31·8	33·2
No. 3	59·1	61·8
No. 4	37·1	38·1
No. 5	46·8	48·5

(2) Mica.

The name mica is applied to a certain group of minerals which can be easily split into thin sheets or laminæ. These minerals are of a refractory nature and vary in composition, depending upon the position of the deposits. The main sources of mica are Canada, the United States, and India.

This mineral is placed on the market under various names, such as white, ruby, green, and amber mica. It is one of the few minerals found in a natural state which has so many properties in its favour as an insulating material. It has a high dielectric strength and good heat-resisting properties, and its power of absorbing moisture and oil in a single splitting is practically non-existent. The dielectric strength of various micas varies from 2 to 4 kV per mil (0·001 inch), the lower

values being given by amber micas, and the highest by the white and ruby varieties.

The temperature-resisting properties of mica are very good, and it is safe to use this material up to several hundred degrees C. ; the detrimental effects of high temperature are not shown until such a heat is reached that the material begins to lose its water of crystallization. After this temperature the substance appears to disintegrate and becomes a powder losing all its electrical and mechanical properties. Mica is used to a great extent in connection with cloth and paper, the splittings being stuck on to these backings. Various compound materials are manufactured in this manner.

The uses of mica as an insulator.—Mica is put to many uses in the electrical engineering industry, and it is proposed to discuss briefly the various methods of converting the raw product into the insulating material as it is finally used on the machine, etc. In the earlier days of insulation manufacture, the machines were so small that pure mica could be used, but as they became larger other methods had to be adopted and the first to realize and cope with this difficulty were the Micanite and Insulator Company. Built-up mica commutator plate was invented and placed on the market in 1892 under the trade name of "Micanite."

During late years many manufacturers have made mica plate similar to micanite, and many other forms of material in which mica is the basic constituent, the

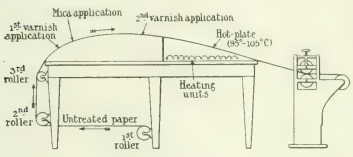

FIG. 1.—Machine for the manufacture of micafolium.

mineral being employed in combination with paper, cloth, silk, and many other forms of treated or untreated fabrics. One of the most important uses of mica with paper is in "micafolium," a description of the manufacture of which is given below.

Micafolium.—The manufacture of this material is usually carried out upon a long table-like structure (see Fig. 1). Underneath this table and situated near the middle is a roller which carries the untreated paper. The material comes from this roller and passes to the end of the table where it comes in contact with a second roller, the direction of the material being now altered. The gap between the first and second roller is for the purpose of removing creases from the paper. After passing upwards at the end of the table the material comes into contact with a third roller. At this juncture the paper comes into contact with the top surface of the table, which is slightly curved, the highest point of the curve being in the middle. After leaving the third roller and coming on to the curved platform, a coat of varnish is brushed on the paper, usually a liquid solution of copal or shellac gums in spirit ; it is essential that it be of a quick air-drying nature. After the application of the varnish and before it has had time to dry, mica splittings are placed by hand on the sticky surface, a single overlap being the most frequent method of building. The treated paper then slowly passes along the platform at the rate of about 5 to 7 inches per minute, until it reaches the highest point of the curve. Having reached this position the bottom coat of varnish to which the splittings are stuck is almost dry, and a second coat of a thinner varnish is then brushed over the top surface of the mica. After this operation the paper proceeds down the slope and passes over a hot-plate, which effectually completes the drying operation. This heated portion is maintained at a temperature varying from 85 to 105° C. It is usual to employ small electrical resistance units, although gas heating is equally efficient. This method of drying the varnish, although almost universally employed, is not entirely satisfactory, because the heat primarily comes in contact with the untreated bottom side of the paper and not with the top which holds the undried varnish. It has been suggested by certain authorities that a more efficient method of drying would be to blow hot air down on to the top surface of the material ; a machine thus constructed would have to be provided with fixtures to carry away the air after it had been in contact with the undried micafolium, as otherwise the fumes would be objectionable and render working on the machine a matter of great discomfort. After passing over the hot-plate the dried material leaves the table between two rollers and passes on to a final roller where it is wound until the requisite quantity has been manufactured.

Various materials.—Many other materials of the same nature as micafolium are manufactured with other fabrics than paper as bases, among the most important being :

(*a*) Mica on cloth.
(*b*) Mica on silk.
(*c*) Mica on varnished cloth.
(*d*) Mica on varnished silk.
(*e*) Mica on pure pulp paper.
(*f*) Flexible mica.

In all materials, with the exception of micafolium, the process is almost invariably carried out entirely by hand. The mica splittings are in most cases stuck upon the material which is being used as a base and then the required thicknesses are built up with the aid of various cements and varnishes. A varnish with a low value of acidity should be used for this class of work.

In the case of flexible mica sheets no paper or cloth is used and the material consists solely of mica splittings and varnish.

Mica plate.—The manufacture of mica plate is very similar to that of flexible mica, except that the varnish or cement used in this case has much better drying properties and usually does not contain even a small percentage of the oils, such as castor oil, which are added to the varnishes used for sticking flexible mica in order to give the finished material its required pliancy.

(3) Fibrous Materials.

There are a great many fibrous materials used for the purpose of insulating various portions of electrical machines and apparatus. The most important are:

(*a*) Paper.
(*b*) Cloths (cotton, linen, and silk).
(*c*) Boards (press-spahn, fullerboard, etc.).

All these materials have moderate insulating properties when dry and clean, but as they are of a hygroscopic nature it is always necessary to protect them by a coat of varnish and oil. The adaptability of fibrous materials to wrapping and binding processes, combined with the comparative ease of impregnation by means of the aforementioned liquids, is one of the most important factors in their use. The even qualities and close structure of papers and cloths favour their use in this direction. There are many varieties of paper and cloths used as insulators. In the case of cloths they are usually known by names which are self-

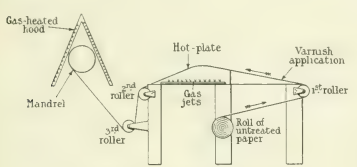

Fig. 2.—Type A cylinder-winding machine.

explanatory, such as cotton, silk, linen, etc. In the case of papers, however, there are various classes.

The most widely used varieties of papers include:

(*a*) Bond (kraft).
(*b*) Greaseproof.
(*c*) Manilla.
(*d*) Leather.
(*e*) Japanese.
(*f*) Imitation Japanese.
(*g*) Rope.
(*h*) Rag.

The majority of these papers are manufactured from wood-pulp, with the exception of rope paper, rag papers, and Japanese rice papers, the last-named of which is made from bamboo fibres. Japanese tissues are made from paper mulberry fibre.

Insulating boards may be separated into two distinct classes:—

(1) Press-spahn, fullerboard, etc., made by a paper-making process. The materials used vary, but, generally speaking, the Continental practice is to use wood-pulp. The American practice is to use rags, etc., and British manufacturers largely use hemp-bags, etc.

(2) Fibres, leatheroids, etc., made from wood-pulp by a chemical process and then pressed.

Paper, cylinder and tube-winding machinery.—There are various forms of machines used for the purpose of winding paper in such a way as to form cylinders and tubes, and it is proposed to describe briefly one of the most important types. In this type of machine (see Fig. 2) the original material employed is untreated paper, although the machine can be adapted to treated paper. The salient points of this type consists of a heated platform and the actual winding gear. The roll of untreated paper is situated beneath the hot-plate, from which it is passed over a guide roller and carried along over the heated portion, the temperature of which is about 100° C. These plates are usually heated by gas, and care has to be taken not to exceed a safe working temperature, otherwise the paper becomes charred and loses its mechanical strength. As soon as the paper passes over this first guide roller, varnish is applied to the surface either by brushing or by means of a spray. During its passage over the hot-plate the varnish dries, and by the time the paper has completely passed over the plate and reached the second guide roller the surface is perfectly dry. The paper then passes under a third roller and thence on to the mandrel, which is a long steel tube. In this type of machine the mandrel is heated by means of a hood-shaped device, containing numerous gas jets. The temperature for large cylinders is about 130° C., and slightly lower for smaller ones. A great advantage of this type of heater is the uniformity of distribution of heat along the whole length of the structure. When the paper reaches the mandrel it is carried round and the heat is sufficient to cause the varnish to become "tacky" and thus stick one layer to the next. This process is continued until a wall of sufficient thickness has been attained. During the process of winding a certain pressure is kept upon the paper by means of the hood-shaped heating arrangement, this acting both as a heater and a means of ironing the paper as it is carried round. Great care has to be taken that this hood does not tear the paper. When the required thickness has been attained the machine is stopped and the completed cylinder removed from the mandrel. The edges are then trimmed. Sometimes the cylinders are placed in an oven and baked, but this depends chiefly upon the varnish which has been used.

Defects.—To guard against imperfect cylinders the following precautions should be taken:

(*a*) The correct amount of varnish must be applied, or the percentage of varnish on the treated paper must be kept constant.
(*b*) The temperature of the mandrel should not be allowed to fall below about 100° C.
(*c*) The winding should be carried out at a moderate speed.
(*d*) Sufficient pressure and tension should be kept on the paper during winding.

After the cylinder has been wound it is very frequently baked, and this extra process usually has the effect of raising the dielectric strength. The question of baking in the case of shellac, or shellac and copal cylinders, is supported by some authorities and not by others. When, however, the cylinder is treated with a varnish made from any synthetic resin, it is generally recognized that baking will carry the condensation of these synthetic substances further and thus result in a product of greater homogeneity being formed.

In the author's opinion the process of baking is advantageous in all cases, although it may not always be necessary. The following table gives an example of the effect of baking.

Time of Bake	Breakdown Voltage	Thickness	Breakdown Voltage per mil	Average Pressure
hrs.	volts	in.	volts	volts
5	58 000	0·105	552	552·0
5	58 000	0·105	552	
10	70 000	0·105	666·6	704·8
10	78 000	0·105	743·0	

A frequent source of trouble in these paper-wound cylinders is excessive mechanical pressure when in position in the finished apparatus, particularly at temperatures between 80 and 90° C.

The varnish, if of a shellac or copal nature, softens and is squeezed from the cylinder by these forces, which are frequently exerted upon tubes when placed between the high-tension and low-tension windings of transformers, due to the clamping and tightening up. The following table gives an idea of the effect upon the dielectric strength of this class of insulation, due to mechanical pressure. The tests were taken on various portions of one cylinder, the tension referred to being applied between the electrodes.

Tension	Breakdown Voltage	Breakdown Voltage per mil	Remarks
Very loose ..	70 000	610	Tests carried out in hot oil (80 to 90° C.)
Loose	66 000	606	
Moderately tight .	65 000	566	
Slightly tighter ..	63 000	547	
Tight	55 000	463	

Tube-winding machines.—The methods described for winding cylinders can also be applied to tube-winding machinery, with slight modifications due to the reduced size of the product.

Paper insulators.—Tube-winding machines are also used to manufacture very thick-walled tubes upon a small mandrel. From these tubes insulators of various shapes are turned on a wood-working lathe. This process is necessarily very wasteful and the finished products are expensive. This class of insulation is usually employed on switchgear.

Cloth.—Cloth is widely used for insulating purposes, especially for taping purposes.

Boards.—Fullerboard, press-spahn, etc., are extensively used for insulation, either in their normal condition or after boiling in oil and varnishing. Their uses are many and include insulating washers between transformer coils, separating pieces, slot linings, etc.

Testing of fibrous materials.—The main tests include the following:

(1) Electrical.
  (*a*) Dielectric strength.
  (*b*) Insulation resistance.
(2) Mechanical.
  (*a*) Tensile strength.
  (*b*) Bursting strength.
(3) Physical.
  (*a*) Loss on heating.
  (*b*) Porosity.
(4) Chemical.
  Acidity.

The above tests include all the most important properties which it is often necessary to investigate on new materials, and certain of them should always be conducted on consignments of material as a matter of routine in order to check the quality of supplies. It is, of course, unnecessary to carry out all these tests each time, as certain results will be a sufficient guide as to the other properties of the material under examination.

(4) Liquid Insulation.

There are roughly two main heads, viz.:

(*a*) Those used for insulation in a liquid form.
(*b*) Those applied in a liquid form and fulfilling their function as an insulator when dry.

The material of the greatest importance in class (*a*) is oil. This is used as a medium for immersion of many classes of apparatus, chiefly switchgear and transformers. Carbon tetrachloride (CCl_4) is also slightly used, but almost entirely in connection with high-tension fuses, from which it will be seen that its use is very limited compared with oil. Class (*b*) consists of varnishes and paints which are used for the treatment or preparation of various insulating materials. In this class oil also plays a large part, although drying oils having characteristics different from those previously mentioned are employed. Many kinds of varnish are employed in the electrical industry, depending upon the work which the finished machine or piece of apparatus has to perform.

Varnishes, etc.—The properties of various varnishes, etc., depend upon the uses to which the liquids are to be put, and may be classed as follows:

(1) Dipping baking varnishes.
(2) Dipping air-drying varnishes.
(3) Impregnating varnishes.
(4) Finishing varnishes.
(5) Sticking varnishes.

The desirable properties of all varnishes are the same although it is impossible for each grade to embrace all the good qualities, and certain characteristics have to be sacrificed in order to bring out others to a greater degree of perfection, the most essential points being:

(1) Minimum drying time (in either air or oven).
(2) Good ageing properties.
(3) High dielectric strength.
(4) Low acidity.

Dipping baking varnishes should dry in an oven maintained at about 80° C. for not longer than 8 to 10 hours. This short time necessitates the addition of a certain quantity of driers and various other more or less volatile liquids; all these ingredients tend to lower

the ageing properties of the varnish. It would, however, be very inefficient from the point of view of production to make all varnishes very good in the way of ageing, hence varnishes which are to be used in connection with apparatus which is likely to meet with a great amount of vibration when in service are the only ones which require flexibility. This property is attained by the addition of greater amounts of oil and smaller quantities of driers. This shows how one property has to be sacrificed in order to bring out another to a marked degree, as it is impossible to make a very rapid drying varnish which has at the same time great flexibility (i.e. good ageing properties).

In the case of finishing varnishes rapid drying is essential, and hence spirit-base varnishes are used which will age in 20 to 40 minutes, whereas the flexible baking varnishes frequently show no signs of age even after periods sometimes exceeding 1 000 to 1 500 hours when tested on paper or other varnish-absorbing material in a laboratory.

The methods of application also vary with the class of work which the finished product will have to perform.

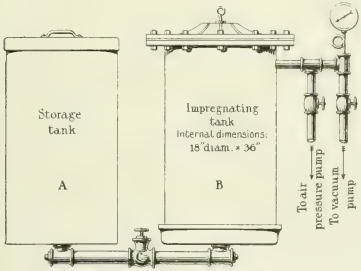

FIG. 3.—Small bakelite coil-impregnating apparatus.

The common practice with coils, etc., is to dip them in large vats containing the varnish. The coils are usually placed first in drying ovens, and are then dipped and again placed in the ovens where the drying process is completed. The ovens are maintained at a temperature of about 80° C. and usually constructed so as to be supplied with a blast of hot air. The effect of this circulation is to increase the speed of oxidation and thus reduce the time of drying. The methods of applying varnishes are very similar, and comprise dipping, brushing or spraying. The greatest variation is in the case of synthetic varnishes, where it is usual to impregnate the coils and then "bakelize." By the courtesy of the General Bakelite Co., the author has been able to describe a characteristic process employed with varnishes made from synthetic resins, of which bakelite was the original.

The coils to be treated are placed in an impregnating apparatus (see Fig. 3). This consists essentially of two tanks, A and B. A is the storage tank for the varnish, and B the chamber in which the actual process of impregnation takes place. This second chamber is connected by means of pipes to pressure pumps and vacuum pumps, and is so constructed that the lid can be raised. The latter is fitted with bolts all around the circumference, to enable it to withstand the comparatively high working pressures. Chamber A is not so strongly built, as it is not subjected to any pressure. After preliminary baking to expel any excess of moisture for about 3 hours at from 107 to 110° C., the coils are placed while hot in chamber B. The stop-cock at C is closed and the air rapidly drawn off until a vacuum of about 28 inches has been attained. This process should take about 20 minutes, so that any air trapped in the coil may be drawn out. When it is considered that the vacuum has been maintained for a sufficient length of time, the stop-cock at C is opened and the chamber flooded with varnish, until the required level has been reached. C is then closed and a pressure of from 60 to 100 lb. per sq. in. applied. This pressure should extend over a minimum period of 3 hours, but should be released for 5 to 10 minutes after each hour in order to liberate any confined air. When this impregnation is complete the varnish is driven back into the storage tank, and the coils are removed and placed on

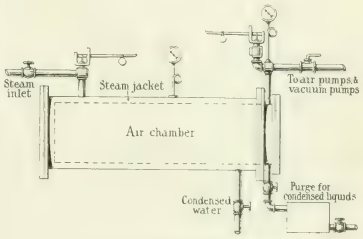

FIG. 4.—Bakelizer and connections.

racks to drain. Sometimes the coils are now placed in an oven at a temperature of 80° C., and baked. This is not essential but is advantageous as it gives a surface hardness which tends to prevent the varnish from oozing during the subsequent bakelizing process.

A bakelizer (see Fig. 4) is an apparatus in which coil baking or heating is carried out under pressure. It consists of a steam-jacketed chamber provided with air- and vacuum-pump connections. The apparatus is usually designed to withstand a working pressure of 150 lb. per sq. in. and a vacuum of 28 inches, while the steam pressure in the jacket is 80 lb. per sq. in. On the completion of impregnation and possible preliminary drying and baking, the coils are placed in the bakelizer under a pressure of about 100 lb. per sq. in. and baked for 3 hours, the pressure in the steam jacket being about 5 lb. per sq. in. The steam pressure is then raised to about 60 lb. and a further 3 hours' baking is given. At the end of this time the apparatus is evacuated and a further 3 hours' baking in vacuum is carried out. The purpose of this vacuum-drying is

to carry away any moisture formed during the process of bakelizing. A certain amount is bound to form as the condensation of the synthetic resins nears completion, as the final product is a higher anhydride than the original. This process is typical of the uses of synthetic varnish and is known by the General Bakelite Co. as the "Single Vacuum Impregnation Process." They recommend other methods which are modifications of the one described and are known as:

(*a*) Single dipping.
(*b*) Double dipping.
(*c*) Single vacuum impregnation.
(*d*) Double vacuum impregnation.

Testing of liquid insulation.—The most usual tests include the following:

Oil tests:—Dielectric strength.
Sludging properties.
Acidity.

Varnish tests:—Specific gravity.
Viscosity.

PROCEEDINGS OF THE INSTITUTION.

670TH ORDINARY MEETING, 3 NOVEMBER, 1921.

(Held in the Institution Lecture Theatre.)

Mr. Ll. B. Atkinson, Past-President, took the chair at 6 p.m.

The minutes of the 49th Annual General Meeting and of the Ordinary Meeting of the 31st May, 1921, were taken as read, and were confirmed and signed.

A list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

The following lists of donations were taken as read and the thanks of the meeting were accorded to the donors.

Benevolent Fund.—C. T. Allan; R. Andrews; A. W. Ashton; J. W. Atkinson; J. C. Bentley; L. Birks; H. E. Blackiston; R. Bruce; E. T. Clifford-Jones; J. K. Clifford-Jones; P. C. Collier; J. Colquhoun; E. D. J. Davies; P. G. Davies; The Diesel Engine Users' Association; E. Dixon; J. Dubbin; W. Duncan; A. H. Dykes; The East Midland Sub-Centre (per J. F. Driver); F. J. Edgar; H. S. Ellis; A. R. Everest; C. F. Fowler; H. G. Gilliland; J. R. W. Grainge; H. W. Gregory; P. H. Gwynn; F. de B. Hart; J. S. Hasdell; Messrs. W. T. Henley's Telegraph Works Co., Ltd; R. S. Hobson; J. B. Hudson; E. M. Hughman; P. Hunter-Brown; V. R. Hurle; S. Insull; The Informal Meetings Committee (per F. Pooley); E. S. Jacob; R. G. Jakeman; E. Johnson; M. J. Kalapesi; P. C. Kerr; H. W. Kolle; W. E. Lane; H. L. Leach; H. I. Lewenz; The Liverpool Sub-Centre (per O. C. Waygood); R. Lye; A. E. McColl; R. W. Manifold; B. W. Mitchell, Junr.; C. E. Morgan; A. R. Murray; E. P. Neate; R. O. B. Neil; F. T. Parker; G. W. Partridge; J. Paterson; T. R. Paver; C. J. D. Pocock; The Post Office Engineering Department Staff (per Sir W. Noble); E. S. Ritter; A. Roberts; A. E. Severn; D. C. Sharp; H. G. Shoolbred; E. S. Shoults; F. Simpson; F. A. Sleath; G. T. Thomas; G. Thomas-Davies; J. A. Troughton; R. Turner; The "Twenty-Five" Club; V. Venkataram; H. C. Wellden; The Western Centre (per W. Collins); H. K. Whitehorn, and T. Wood.

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Statham; W. J. Thorrowgood; A. P. Trotter; The United Engineering Society, New York; The United States Bureau of Standards; The United States Department of Commerce; Prof. M. Walker; T. F. Wall, D.Sc.; L. E. Wood.

The Chairman: It is my pleasure to announce formally that a Royal Charter of Incorporation has been granted to this Institution. The Charter is on this table and it is of interest to mention that a Past-President, Sir John Snell, and our Honorary Treasurer, Sir James Devonshire, were present at the actual placing of the seal on the document. I believe that it was the first occasion on which the Royal Seal has been placed on a document in the presence of those interested in such document. I am also pleased to announce formally what is already well known, that His Majesty the King has graciously consented to become the Patron of the Institution. The next announcement which I have to make is that the Council have decided to keep the Library open in future on two evenings each week until 9.30 p.m., or alternatively one evening a week and Saturday afternoon until 5 p.m. In order to ascertain which days are most favoured by members, the Library will be kept open every weekday evening and every Saturday afternoon until Christmas, dating from Monday, 14th November.

The Premiums and Scholarships (see *Institution Notes*, No. 26, page 22, May 1921, and No. 22, page 3, December 1920, respectively) awarded during the Session 1920–21 were then presented by the Chairman to such of the recipients as were present.

The Chairman: It only remains for me to ask our new President, Mr. J. S. Highfield, to take the chair.

The chair was then vacated by Mr. Ll. B. Atkinson and taken by Mr. J. S. Highfield amid applause.

Sir John Snell: The first thing that I should like to do would be to congratulate my old friend, Mr. Highfield, on his accession to the chair. If a fine courage and sterling good sense are going to be helpful to the President of this Institution, then our newly elected President will serve the interests of the Institution very faithfully during his coming year of office. I rise, however, with the object of moving a resolution of thanks to our retired President, Mr. Llewellyn Atkinson. Those who have had the privilege of listening to his speeches during his year of office must have been struck by the statesmanship and deep thought which they have revealed. I should like to refer briefly to the Royal Charter of Incorporation which has been granted to this Institution, and to His Gracious Majesty's Royal Patronage of the Institution. The untiring industry which Mr. Atkinson has given to this Institution during his term of office has been fittingly crowned by these two great events. I venture to think that half a century hence when the centenary of this Institution is being celebrated, the members will look back upon the year 1921, the 50th year since the foundation of the Society of Telegraph Engineers, as being an epoch-making year in the history of the Institution, and I am of the opinion that the name of Llewellyn Atkinson will become historic. It is especially pleasing to think that our beloved King has given his Royal Patronage to the Institution. It shows that his untiring efforts for the good of the Realm and of his people are typified once more by the active interest which he has given to this growing industry. I have great pleasure in moving "That the best thanks of the Institution be accorded to Mr. Llewellyn B. Atkinson for the very able manner in which he has filled the office of President during the past year."

Mr. C. H. Wordingham: It is with peculiar pleasure that I rise to second the vote of thanks which Sir John Snell has proposed. It is rare to find such a combination of commercial and administrative ability with scientific attainments of the highest order as we have in Mr. Atkinson. It is rarer still to find combined with those qualities conspicuous tact and never-failing devotion to hard work for the Institution. All those qualities are combined in Mr. Atkinson in a high degree. Only those who have had the honour of being President and who have attended the Council meetings know how arduous are the duties of the President. Mr. Atkinson has been at the beck and call of the Institution every hour of the time he has been in office. Nothing has been too great for him to tackle; no work has been too hard for him to do. He will live in the memory of all the members of the Institution, chiefly, I think, by his having obtained for the Institution the Royal Charter. But he will live also in the hearts and affections of those of his friends who, like myself, have known him intimately since his student days, as a sterling friend for whom we have the sincerest admiration. I therefore formally and very heartily second the resolution.

The resolution was then put by the President, and carried with acclamation.

Mr. Ll. B. Atkinson: In moving and seconding this vote of thanks, Sir John Snell and Mr. Wordingham have used words which I cannot help feeling are coloured as much by their friendly goodwill towards myself as by my merits for the thanks which they have showered upon me. I do not disguise the satisfaction it has been to me that during the jubilee year of the Institution, in which I have had the good fortune to be your President, we have achieved results in particular directions which have long been in our minds and hearts. The honours and the recognition that we have received are, however, the result of the 50 years of work of all the members of the Institution, past and present, of all the Councils that have gone before, and of all the Presidents who have been in the chair before me. All those efforts and results have been gradually concentrating and converging, and it was my good fortune simply to be the final instrument which translated those efforts into the results we have achieved. If beyond this there is any special direction in which I have been fortunate, it is that I have succeeded in attracting, for one reason or another, the united and undiluted goodwill, not only of all the members of the Institution of every class, but of a great many men of power and position in our Industry who do not happen to be members of the Institution. That to me has been one of the joys of being President. It has left an impression on my mind that will never be effaced—the feeling that throughout the whole of the

past year, the whole Institution and those outside our Institution in the electrical industry, have moved together to bring about the results that have been achieved. In a recent issue of the *Journal* (No. 302) I thanked all our members and others. In those few words of thanks I took the opportunity—and I desire to take it again to-night—of saying that, with regard to the Charter, I have been greatly helped by all our Past-Presidents and the Council, but above all by Sir James Devonshire, who has stood by my side at every moment, and with whom I have discussed the matter every hour, I might say, of almost every day for some months. I therefore take this opportunity of saying again that I personally, and the Institution as a body, owe him a debt which we cannot repay in any other way than by saying what our feelings are on the subject. I tendered also in the *Journal*, and I now take the opportunity of doing so again—my thanks to our Secretary, Mr. Rowell, and all his staff for the ready help which they have rendered to me on every occasion. I hope to be in the future, as in the past, of some help to the Institution, and with that thought in all our minds I need say no more than that we shall now go forward under the leadership of our new President, Mr. Highfield.

The President then delivered his Inaugural Address (see page 1).

Colonel R. E. B. Crompton : Our new President's Address deals with the difficult topics of our time and we must agree that he has put them before us so clearly and thoughtfully that, when printed in the *Journal*, we shall be able to read them with profit, and I hope, with comfort for our future. The general effect of his Address has been to make me think, and I believe that all who are here will feel as I do, that we electrical engineers, above all others, must be armed with trained powers of observation leading to thought and deduction therefrom. I consider that we electrical men to-day are in the fortunate position of supplying the electrical energy which is now wanted everywhere and to an extent hitherto undreamt of. I believe that the future progress of our civilization depends very largely on the extent to which energy can be supplied all over rural England. I hope to live to see the work now carried out in large towns, where labour is crowded together in unhealthy surroundings, at no distant date spread widely over the country. I foresee the increase of village industries as in Switzerland ; this can only be done by cheap electrical supply and, although we may hold different opinions as to whether this will be by water power or by burning our fuel, it is practically certain that the next decade will be one of wide electrical power distribution. At this late hour I can say no more than to thank the President most heartily for his thoughtful Address and, in order that we may read it and study it as it deserves to be studied, I move " That the best thanks of the Institution be accorded to Mr. John S. Highfield for his interesting and instructive Presidential Address, and that, with his permission, the Address be printed in the *Journal* of the Institution."

Mr. R. T. Smith : I have much pleasure in seconding the motion that has just been proposed. One of the points clearly brought out in the President's Address is that electricity supply is not only a public service but also a very important trade on which many other trades depend. In the past the restrictions which have been imposed on the electricity supply industry, chiefly from the point of view of regulating a public service, have made it almost impossible for electricity supply to be the successful trade that it ought to be. The principles of trading are not studied in this country as much as they deserve to be by people who are not traders, and sometimes not even by people who are ; and I am sure that this Address will stimulate many of us to make up for that deficiency by a further study of, and interest in, the trade of electricity supply.

The resolution was put to the meeting by Mr. Ll. B. Atkinson, Past-President, and was carried with acclamation. After the President had briefly replied, the meeting terminated at 7.45 p.m.

16TH MEETING OF THE WIRELESS SECTION, 9 NOVEMBER, 1921.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The minutes of the meeting of the Wireless Section held on the 8th June, 1921, were taken as read, and were confirmed and signed.

A vote of thanks to Dr. W. H. Eccles, F.R.S., for his services as Chairman of the Wireless Section during the past two Sessions was proposed by the President, seconded by Major J. Erskine Murray, and carried with acclamation.

Professor G. W. O. Howe, D.Sc., Chairman of the Wireless Section, then delivered his Inaugural Address (see page 67).

A vote of thanks to Professor Howe for his Address, proposed by Dr. W. H. Eccles, F.R.S., and seconded by Mr. A. A. C. Swinton, F.R.S., was carried with acclamation, and the meeting terminated at 7 p.m.

INAUGURAL ADDRESS TO THE WIRELESS SECTION

By Professor G. W. O. Howe, D.Sc., Member.

(*Address delivered 9th November*, 1921.)

My first duty this evening is to express my appreciation of the honour conferred upon me by the Wireless Section in electing me to serve as Chairman. It is now about two years since the Section was formed and I venture to say that no step which the Institution has ever taken has been more signally and immediately successful. Every meeting has been well attended, some, in fact, so well attended that it was difficult to realize that they were sectional meetings. The papers have maintained a high standard and have been followed by interesting discussions. Those who took part in the formation of the Section, and those who have served on the Committee, know to what a large extent this success has been due to the untiring energy and resourcefulness of our retiring Chairman, Dr. W. H. Eccles, F.R.S. The time was peculiarly opportune for the formation of the Section; the war had just concluded and great developments had taken place in every branch of the subject, but very little had been published or openly discussed. The phenomenal attendances at some of our meetings showed the widespread desire to learn something of these developments. The war not only led to the training in radio-telegraphy of a large army of highly-skilled enthusiasts, but also caused engineers and physicists in general to take a greater interest in a subject which had accomplished so much and which embodied within itself such an intimate combination of engineering and pure science.

The papers read before the Section have been largely descriptive of the development of radio-telegraphy and telephony in the various branches of the Services. They have dealt with the subject mainly from a descriptive and qualitative point of view. I think that we are now entering on a new period of development—a period of refinement in design, of accuracy of measurement, of careful analysis of all losses, of improvement and quantitative research in every detail. A large number of scientists are engaged on the various problems; the manufacturing firms and the administrative heads of Government Departments all recognize the importance of the work and have established Research Departments. All this promises well for the future development of radio-telegraphy in this country and for the future of the Wireless Section of this Institution.

With these introductory remarks I turn to the subject of my Address. It is usual for a Chairman in his Address to deal with some aspect of the subject in a broad, general way, reviewing, for instance, historical developments or economic possibilities. I propose to adopt a more modest plan, to leave history and politics, economics and education severely alone, and merely consider a simple piece of apparatus from a purely scientific point of view. I regret that I have not had time to carry the investigation as far as I had intended, but I trust that my Address will stimulate others to take up the subject.

If it were imperative that my Address should have a title, it would be "The Effective Self-Capacity, Inductance, and Resistance of Coils."

This is a subject of fundamental importance in every branch of radio-telegraphy, and one in which every wireless engineer cannot but be interested. It is a subject to which I have personally devoted a great deal of thought and on which I have already had the pleasure of reading several papers.

The electrical characteristics of a coil when carrying a high-frequency current are of a complex nature. It is not a simple matter to define precisely what is meant by the inductance and resistance of the coil under these circumstances. I may be excused if I leave the coil for a moment to remark that the definitions of inductance given in textbooks and works of reference are often very unsatisfactory. It is generally stated* that the self-inductance of a straight conductor of length l cm and radius r cm is approximately $2l[\log(2l/r) - 1 + \frac{1}{4}\mu]$. On examination we find that this formula refers only to that portion of the magnetic flux which lies between two parallel planes perpendicular to the wire and passing through its extremities. Now the current in the wire of length l produces a greater magnetic flux outside these planes than between them—the total flux is in fact infinite—and, however useful the above expression may be in subsequent calculations, there appears to be no justification for calling this quantity the self-inductance of the conductor.

Similarly for the mutual inductance between two parallel wires of length l, radius r and distance apart d. This is defined † as the number of lines of force due to unit current in one conductor which cut the other conductor when the current disappears. This presupposes not only a knowledge of the flux at every point in space, but also of the path by which it got there, else how can it be known whether it cut the other conductor? As a matter of fact, the formula given ignores all flux except that between the two parallel planes normal to the wires through their extremities, and the amount of the flux thus ignored is infinitely great. For the mutual inductance of two straight conductors placed end to end in the same straight line a formula is given ‡ which is obviously inconsistent with the definition of mutual inductance

* *Bulletin of the Bureau of Standards*, 1912, vol. 8, p. 150.
† *Loc. cit.*, p. 151.
‡ *Loc. cit.*, p. 152.

given on the preceding page, since none of the flux produced by one conductor can be said to cut the other. The formula really gives that portion of the flux produced by one conductor which lies between two parallel planes normal to the second wire through its extremities. Electrical engineers and physicists owe a debt of gratitude to the Bureau of Standards for this extremely useful collection of formulæ, and the fact that such inconsistencies are to be found in such an authoritative publication shows the need for careful definitions of the terms self and mutual inductance.

The electric current can only flow in closed circuital paths, and although a path may be partly in conducting material and partly in dielectric material and may, in many cases, be very vaguely defined, the magnetic field produced is the result of the current in the whole circuit. When the current varies the magnetic flux varies and an E.M.F. is induced in the circuit, but I cannot see any justification for earmarking certain portions of the magnetic flux as inducing electromotive forces in certain portions of the circuit. It is very difficult, if not impossible, to define precisely what is

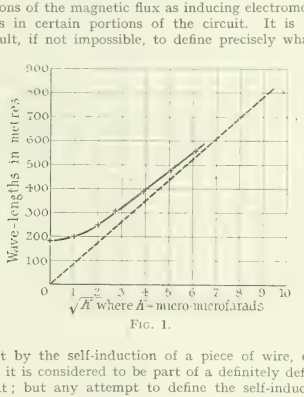

FIG. 1.

meant by the self-induction of a piece of wire, even when it is considered to be part of a definitely defined circuit; but any attempt to define the self-induction of a piece of wire without any reference to the shape and size of the remainder of the circuit, seems to me to be such an unnatural procedure that unreasonable results would necessarily be expected. Neglecting resistance, it is usually understood that the inductance of any part of a complete circuit in which an alternating current is flowing can be obtained by measuring the current and the potential difference between the ends of the part considered. To read the potential difference we must employ a voltmeter, but the reading of this instrument will depend on the positions of the wires connecting the voltmeter, and it is possible to obtain any desired reading by a suitable arrangement of these accessories. As a matter of fact the simple potential theory upon which the conception of potential difference is based is inapplicable to the case of an alternating current, since the work done in moving a charge from one point to another is no longer independent of the path followed. The fact that the conception of potential difference is employed throughout alternating-current work with so little confusion is due to the fact that in the majority of cases either the ambiguity is negligibly small compared with the quantity being measured, or the assumptions made are sufficiently obvious.

I shall now return from this somewhat academic digression and consider a coil carrying high-frequency current. Let us think of a coil used with a variable condenser to form a wave-meter. This coil has a certain self-inductance as determined by measurement with direct or with low-frequency alternating current; if constructed of multiply-stranded fine insulated wire, the distribution of current over its cross-section will not be changed as the frequency is increased, so that if the current in every turn remains unchanged its inductance will not vary. It is well known, however, that as the frequency is increased the current in every turn does not remain the same, but that the current near the central part of the coil is greater than that near the ends, assuming the coil to be symmetrically situated with respect to earth and other conducting bodies. This is due to what is usually called the self-capacity of the coil. When carrying a high-frequency

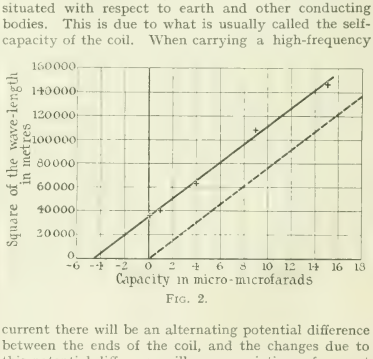

FIG. 2.

current there will be an alternating potential difference between the ends of the coil, and the changes due to this potential difference will cause variations of current along the coil. The question now arises: What is the self-inductance of the coil under these conditions? All definitions of self-inductance assume that the current is the same at all parts of the circuit. In a paper on the "Calibration of Wave-meters" read before the Physical Society in 1912 I described some experiments showing that a very close approximation to the correct frequency was obtained if we assumed that a condenser was connected in parallel with the coil, so that, in so far as its effect on the frequency of the current was concerned, the actual coil with its distributed capacity and non-uniform current could be replaced by an ideal coil with no distributed capacity, and therefore having a uniform current, connected in parallel with a condenser (see Figs. 1 and 2). It appeared to me to be a surprising result that the inductance to be ascribed to this ideal coil could be taken to be the ordinary direct-current inductance of the coil and that the capacity to be considered as connected in

parallel with it was constant and not dependent on the frequency. Some doubt was thrown on this in the discussion, but subsequent experiments in this and other countries* showed that it was true to an extremely high degree of accuracy. Everyone who has to calibrate wave-meters or to make other accurate high-frequency measurements knows the importance of determining the self-capacity of every coil, or what comes to the same thing, its natural frequency or wave-length.

Although it is necessary for practical purposes to represent the self-capacity by a condenser connected across the extremities of the coil, it would appear more reasonable from physical considerations to represent it by a condenser connected across two intermediate points along the coil, between the centres of gravity, as it were, of the positive and negative charges on the coil. Regarding the coil as an auto-transformer, however, this condenser across these imaginary tappings could be replaced by an equivalent condenser of smaller capacity connected across the extremities of the coil.

Various attempts have been made to calculate the natural frequency of a coil from its dimensions and to find some mathematical explanation of the fact that the self-capacity is independent of the wave-length. It is not possible to say that many of these attempts have been very successful. The assumptions made with a view to simplifying the mathematical treatment have often been such as to limit very seriously the general applicability of the results.

I have recently devised a method which is, in my opinion, an advance on any previously published, both as regards the assumptions made and the simple straightforward treatment of the problem. Although this is not the occasion on which to go into the matter in detail, I wish to put before the members the main outline and results in as simple a manner as possible.

As I have already mentioned, at low frequencies the amplitude of the current is practically the same at all points of the coil, but as the frequency is increased the amplitude at the centre becomes appreciably greater than at the ends. This difference increases with an increase in the frequency, until a frequency is reached for which the current at the ends falls to zero. This frequency is the fundamental natural frequency of the coil; it is the lowest frequency to which the coil resonates if suspended in space with no connections.

Under this condition the magnetic flux induces an E.M.F. throughout the coil depending on the shape, size and number of turns, and on the distribution of current along the coil. A quarter of a period after the current at every point has its maximum value, there will be a distribution of charge along the coil, the character of this distribution being determined by the distribution of current. Corresponding to this distribution of charge there will be a distribution of potential and a resulting potential difference between the ends of the coil. The current being zero at this moment, the electrostatic distribution of potential must exactly neutralize the E.M.F. distribution due to the changing magnetic flux. Not only must the total E.M.F. equal the resultant electrostatic potential difference, but the charges and current must be so distributed along the coil that the neutralization occurs at every point.

Although it is theoretically possible to determine the exact distribution from this fact, its practical realization would appear to be extremely difficult and we are compelled to adopt an approximate method. The curve of current distribution along the coil could be represented as a fundamental sine-wave together with a series of odd harmonics and from the nature of the case we should expect the amplitudes of these harmonics to be very small compared with the fundamental. As an approximation we are, therefore, justified in assuming the current to be distributed along the coil according to a sine law.

When the frequency is lower than the natural frequency of the coil and the latter is tuned to this lower frequency by means of a variable condenser connected across its terminals, there will be a current i_x flowing in and out at the ends of the coil, and the sine-wave distribution of current corresponding to the charges on the coil will be superimposed upon a uniform distribution of current corresponding to the charges on the external condenser.

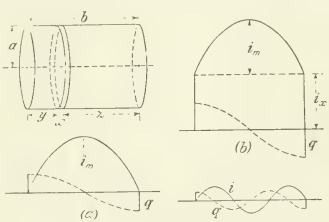

FIG. 3.

The assumption of a sine-wave distribution of current necessitates the assumption of a cosine-wave distribution of charge along the coil. If the length of the coil be b, and the charge per cm of length at the end when at its maximum be q, the total charge on each half of the coil will be $\frac{2}{\pi}q \cdot \frac{b}{2} = \frac{bq}{\pi}$. This must be equal to the excess of the average current at the middle over that at the ends, multiplied by a quarter of a period. If i_m be the maximum value of this excess current at the middle and $f = \omega/(2\pi)$ the frequency, then $\frac{bq}{\pi} = \frac{2i_m}{\pi} \div \frac{1}{4f} \div 3 \div 10^9$ and $i_m = \frac{\omega}{\pi}bq \div \frac{1}{3 \div 10^9}$ amperes. All the symbols represent the maximum values of the alternating magnitudes.

The problem of finding the natural frequency, or the frequency corresponding to any such distribution as those shown at (*a*) and (*b*) in Fig. 3, may be stated as follows:—At what frequency is the induced E.M.F. due to the current equal to the electrostatic potential

* See especially HUBBARD, *Physical Review*, 1915, vol. 6, p. 58.

difference due to the charges? Dealing first with the E.M.F. induced by the magnetic field, it is necessary to find the E.M.F. induced in the whole coil by the current in any small element as shown in Fig. 3.

If M be the mutual inductance between the element and the whole coil and i the current in the element, then the E.M.F. will be equal to ωMi. The total E.M.F. induced in the whole coil by the current in every section will be $\omega\Sigma(Mi)$. The values of M can be found from well-known formulæ* giving the mutual inductance between a single-layer solenoid and a coaxial circle, or from the self-inductances of the parts of the coil, as follows:—

$$M = L_x + M_{xy} - M_{xz}$$

but $$L_{xy} - L_x = L_y + 2M_{xy}$$

and $$L_{xz} = L_x + L_z + 2M_{xz}$$

hence $$M = \tfrac{1}{2}(L_{xy} - L_y) + (L_{xz} - L_z)$$

We have $i = i_m \sin\beta$, when $i_x = 0$.

or $i = i_m(1 + \sin\beta)$, when $i_x = i_m$

or $i = i_m(\gamma + \sin\beta)$, when $i_x = \gamma i_m$.

$b\frac{\beta}{\pi}$ = distance of element from end of coil.

For the E.M.F. induced in the whole coil we have, therefore,

$$e = \omega\Sigma(Mi) = \omega i_m[\Sigma(M\sin\beta) + \gamma\Sigma M].$$

But ΣM is the self-inductance of the whole coil, hence

$$e = \omega i_m[\Sigma(M\sin\beta) + \gamma L].$$

The second term represents the E.M.F. induced by the external current passing through the coil, whilst the first term represents the E.M.F. due to the capacity current within the coil itself.

Taking as an example a coil 20 cm diameter and 20 cm long, wound with 10 turns per cm, the values are shown in the table. The coil is divided into 20 sections each 1 cm long, but since the whole is symmetrical about the middle, only 10 sections need to be calculated.

No. of section	M (10^5 cm)	Sin β	$M\sin\beta$ (10^5 cm)
1	2·025	0·0785	0·159
2	2·325	0·2334	0·542
3	2·526	0·3827	0·967
4	2·671	0·5225	1·397
5	2·785	0·6494	1·808
6	2·873	0·7604	2·186
7	2·940	0·8526	2·507
8	2·985	0·9239	2·755
9	3·018	0·9724	2·934
10	3·030	0·9969	3·020

For the half coil: Total = 18·275.
For the whole coil: Total = 36·549.

The self-inductance of the coil is $54\cdot356 \times 10^5$ cm.

* Rosa: *Bulletin of the Bureau of Standards*, 1907, vol. 3, p. 209.

Turning now to the calculation of the potential difference between the terminals of the coil due to the charges upon it, we have first to determine the potential at a point due to the charge upon a ring or narrow section of the coil. For the potential at a point P due to a charge of ρ per cm of length on a ring of radius a_1 we have (Fig. 4):

$$V = \int_0^{2\pi} \frac{\rho a_1 d\phi}{\sqrt{[x^2 + (a_2 - a_1\cos\phi)^2 + a_1^2\sin^2\phi]}}$$

By putting

$$\theta = \tfrac{1}{2}\phi \quad \text{and} \quad k = 2\sqrt{\left[\frac{a_1 a_2}{x^2 + (a_1 + a_2)^2}\right]}$$

this can be written

$$V = 2\rho k\sqrt{(a_1 a_2)}\int_0^{\pi/2} \frac{d\theta}{1 - k^2\cos^2\theta}$$

$$= 2\rho k\sqrt{(a_1 a_2)}F(k)$$

where $F(k)$ is the complete elliptic integral of the first

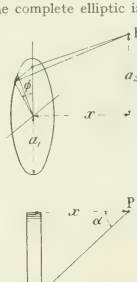

FIG. 4.

kind with modulus k, the values of which can be obtained from any tables of elliptic integrals.

In our case $a_1 = a_2 = a$; $k = \frac{2a}{\sqrt{(x^2 + 4a^2)}} = \sin\alpha$ and $V = 2\rho\,\alpha\,.\,F(\sin\alpha)$, where α is the angle subtended at the point P by the ring (see Fig. 4).

If the charge is distributed over a narrow cylindrical band it may, as an approximation, be assumed to be concentrated on a circle, provided that the distance x is not small compared with the width of the band. Such an assumption is not permissible for the section adjacent to the point P, but it can be shown that the potential due to the ring of width w touching the point P on one side is given by the formula:—

$$V = 2\rho w[\log(8a/w) + 1]$$

The point P is taken on the end turn of the coil, and the potential at this point due to the charges on each

of the 20 sections into which the coil is divided is then worked out as follows:—The charge per cm of length at the ends being q, that at any other point along the coil is $q \cos \beta$. If there are n sections, each of width b/n, the charge on any section is $q(b/n) \cos \beta$ and this replaces the charge $2\pi a\rho$ on the ring. Hence the potential at P due to the section is

$$\frac{qb}{\pi a n} k F(k) \cos \beta$$

and that due to all the sections is

$$\frac{qb}{\pi a}[k F(k) \cos \beta]_{av}$$

the subscript av signifying the average value of the quantity in brackets taken along the coil. Since the potential at the other end will be equal and of opposite sign, the total potential difference will be equal to twice this, viz.

$$V = 2\frac{qb}{\pi a}[k F(k) \cos \beta]_{av} \text{ electrostatic units}$$

$$= \frac{600qb}{\pi a}[k F(k) \cos \beta]_{av} \text{ volts}$$

We have, therefore, the three equations

$$e = \omega i_m[\Sigma(M \sin \beta) + \gamma L]$$

$$i_m = \frac{\omega}{\pi} bq \frac{1}{3 \times 10^9}$$

$$V = \frac{600qb}{\pi a}[k F(k) \cos \beta]_{av}$$

from which $\omega^2 = \dfrac{1\,800 \times 10^9}{a} \cdot \dfrac{[k F(k) \cos \beta]_{av}}{[\Sigma(M \sin \beta) + \gamma L]}$

and $\omega^2 La = 1\,800 \times 10^9 \dfrac{[k F(k) \cos \beta]_{av}}{\left[\dfrac{\Sigma(M \sin \beta)}{L} + \gamma\right]}$

which depends only on the shape of the coil and not on its size or the number of turns.

If the capacity of the condenser connected across the terminals of the coil be C_x and the effective self-capacity of the coil be C_s, the total effective capacity $C = C_x + C_s$.

Now, since $\omega^2 LC = 1$,

$$C = \frac{1}{\omega^2 L} = \frac{a\left[\dfrac{\Sigma(M \sin \beta)}{L} + \gamma\right]}{1\,800 \times 10^9 . k F(k) \cos \beta_{av}}$$

and, since $i_x = \omega C_x V$,

$$C_x = \frac{i_x}{\omega V} = \frac{\gamma i_m}{\omega V} = \frac{a\gamma}{1\,800 \times 10^9 . k F(k) \cos \beta_{av}}$$

Hence $C_s = C - C_x = \dfrac{a}{1\,800 \times 10^9} \cdot \dfrac{(1/L)\Sigma(M \sin \beta)}{[k F(k) \cos \beta]_{av}}$

The effective self-capacity, that is, the capacity which we may assume to be connected across the terminals of the coil to replace the distributed capacity, depends only on the radius and on the shape of the coil, but is independent of γ and, therefore, of the frequency.

In arriving at this result, the effect of dielectrics other than air has been neglected and the assumption has been made that the current has a sine-wave distribution along the coil.

The values of $(1/L)\Sigma(M \sin \beta)$ and $[k F(k) \cos \beta]_{av}$ have been calculated for three shapes of coil, viz. $b/a = 1$, $b/a = 2$, and $b/a = 4$, and the results are as follows:—

	$b/a = 1$	$b/a = 2$	$b/a = 4$
$\frac{1}{L}\Sigma M \sin \beta$	0·664	0·672	0·673
$[k F(k) \cos \beta]_{av}$	0·610	0·608	0·585
C_s in micro-microfarads ..	$0·605a$	$0·614a$	$0·64a$

It is seen that the self-capacity varies but little with the shape of the coil and is directly proportional to its radius for a given shape.

In my paper before the Physical Society in 1912 I showed that in a set of four coils, each of 2 millihenrys, but varying in diameter from 5 to 20 cm, the self-capacity varied only between 0·52 and 0·66 times the radius over this extreme range.

It is of interest to determine the frequencies corresponding to various values of the ratio $\gamma = i_x/i_m$. If $\omega_0/(2\pi)$ be the natural frequency of the coil alone, and $\omega_1/(2\pi)$ the frequency when an external condenser is connected across the coil, then it is seen from the above formulæ that

$$\left(\frac{\omega_0}{\omega_1}\right)^2 = \left(\frac{\lambda_1}{\lambda_0}\right)^2 = \frac{\Sigma(M \sin \beta) + \gamma L}{\Sigma(M \sin \beta)} = 1 + \gamma \frac{L}{\Sigma M \sin \beta)}$$

For a coil in which $b = 2a$, $(1/L)\Sigma(M \sin \beta) = 0·672$, then, if

$$\gamma = 1, \quad \lambda_1 = 1·58\lambda_0$$
$$\gamma = 2, \quad \lambda_1 = 1·99\lambda_0$$
$$\gamma = 10, \quad \lambda_1 = 3·99\lambda_0$$

so that when the wave-length is four times the natural wave-length of the coil, the current at the middle is 10 per cent greater than the external current.

Drude found experimentally that the natural wave-length of a single-layer coil with a length equal to the diameter was 2·54 times the length of wire on the coil. This gives a wave-length 7·4 per cent lower than that calculated from the above figures. This discrepancy suggests that the current distribution may differ considerably from that assumed.

A closer approximation may be made by assuming that the current distribution may be analysed into a fundamental and a third harmonic. If i_m and i_{3m} are the amplitudes of the fundamental and third harmonic currents at their maximum points, it is possible to calculate the electromotive forces induced by each, both in the whole coil and in any portion QQ′. The potential difference between PP′ and between QQ′ due

to the two distributions of charges can also be calculated. We have now two independent variables, viz. the frequency and the ratio i_{3m}/i_m, and can thus find values such that the induced E.M.F. and the electrostatic potential difference are equal, not only between the points PP′ but also between the points QQ′.

The same method could be employed to calculate the self-capacity of the various types of multi-layer coils which have come into such extended use in radio-telegraphy in consequence of the long wave-lengths now employed and of the necessity of obtaining a large inductance in a relatively small space, but the large amount of labour involved, and the fact that the result when obtained takes no account of the effect of

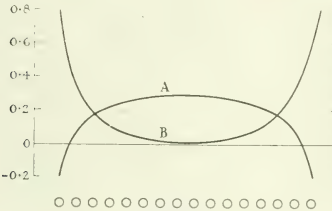

FIG. 5.—Single-layer 16-wire system.

Curve A shows the distribution of effective resistance produced by eddy-current losses due to the proximity of the wires.
Curve B shows the distribution of the losses throughout the system.

dielectrics used in the construction of the coil, make it of doubtful utility.

Turning now to the subject of the resistance of coils, I should like to draw the attention of members to a very important paper on the high-frequency resistance of coils read before the Royal Society in June by Mr. S. Butterworth of the National Physical Laboratory. He establishes a formula for the loss occurring in a wire when situated in a non-uniform magnetic field, and then applies it to calculate the loss in every turn of a 16-turn coil. If a narrow coil be divided into 4 equal sections, it is shown that 93 per cent of the total loss takes place in the outer sections and only 7 per cent in the inner sections. Some tests made at the City and Guilds Engineering College by Mr. A. G. Warren, M.Sc., on the initial rise of temperature at various parts of a coil gave similar results.

It must not be imagined, however, that the end sections have a higher effective resistance than the middle sections, as the contrary is the case. The heavy losses in the end sections are supplied to a large extent by transformer action from the middle sections and thus increase the effective resistance of these sections (Fig. 5). Mr. Butterworth's calculations are based, however, on the assumption that the current is the same throughout the coil, which is no longer true when the frequency approaches the natural frequency of the coil. The distribution of the magnetic flux will then need to be recalculated in order to determine the losses, which, divided by the square of the external current, will give the effective resistance of the coil under those conditions. Mr. Butterworth finds inexplicable discrepancies between the calculated and measured high-frequency resistances of a number of coils, and it may be that further investigations along the lines indicated above will throw further light on the subject.

I have touched upon various topics connected with the high-frequency characteristics of coils, and I have devoted a considerable part of my Address to what some members may regard as very academic and unnecessary details, but I feel sure that the correct design of coils is one which will be forced upon the attention of radio engineers. This applies especially to the coils which have to be inserted in series with an aerial to increase the wave-length. Now that the effective resistance of the transmitting aerial in many large stations has been reduced to about half an ohm, the whole efficiency of the station depends on the design of a loading coil to carry several hundred amperes and to have a high-frequency resistance of a fraction of an ohm. This is an electrical engineering problem of no small magnitude, and one which I hope we may have an opportunity of discussing before this Section. It involves the best design of conductor, the best spacing and arrangement of turns and layers, the best shape of coil, the necessary size and cost to obtain a given resistance, and the precautions which must be taken to minimize losses in neighbouring dielectrics. I trust that those who have been engaged on these and allied problems will bring the results of their work and experience before us at subsequent meetings.

TELEPHONIC TRANSMISSION THROUGH SUBMARINE CABLES.

By A. Rosen, B.Sc. (Eng.), A.C.G.I., Student.

(Abstract *of paper read before the* Students' Section, *4th March*, 1921.)

Summary.

This paper states the nature of the telephone transmission problem, and shows the importance of the attenuation constant.

The effect of varying the line constants is discussed and summarized in a table, and the improvement obtained by the addition of inductance in the form of loading is illustrated. Tables are given of the coil-loaded and continuously loaded cables laid.

It is pointed out that superimposing gives an extra circuit in a 4-wire cable, but is limited by the overhearing.

The introduction of telephone repeaters necessitates a smooth impedance/frequency curve for the cable, and this is more readily obtained with continuous loading.

The paper concludes with a comparison of the two methods of loading, and shows that the balance of advantages is on the side of the continuously loaded cable.

The Telephone Transmission Problem.

This may be briefly stated as follows: Consider a line with a transmitting instrument at one end and a receiver at the other (see Fig. 1); when one speaks into the transmitter an electromotive force is generated which sends an alternating current along the line. It is desired to know the value of the voltage at any point, and its relation to the E.M.F. at the sending end. This E.M.F. varies according to the way in which the membrane of the transmitter microphone vibrates, and the latter is in turn affected by the sound waves in the air produced by the voice. In speaking, the voice creates a complex series of waves, each sound giving rise to its own particular wave; but however irregular the motion of the diaphragm and, consequently, the E.M.F., we may, over any small interval of time, represent these as being built up of a fundamental vibration following the sine law, and of various harmonics of sine form, their frequencies being 2, 3, 4, 5, etc., times that of the fundamental: that is to say, we represent the irregular wave by the components of its appropriate Fourier series. Consequently, it suffices to consider that the form of the E.M.F. generated is a pure sine wave at a definite frequency, and from our results we may make allowance for the practical case by considering the different harmonics in speech and their relative amplitudes. It is necessary first of all to determine what single frequency most nearly represents the human voice from the transmission point of view. The actual frequencies in normal speech range from about 200 to 2 500 periods per second, but it has been found experimentally that 800 periods per second is the mean frequency of speech, taking into account the relative magnitudes of the different harmonics. This value, or more exactly 796 periods per second, which gives the convenient figure of 5 000 radians per second as the angular velocity ($2\pi f$), was chosen by an International Conference in 1910 for all transmission calculations.

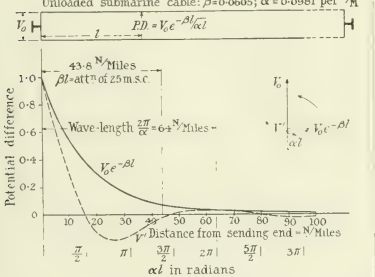

Fig. 1.—Voltage-drop along cable.

Full-line curve shows amplitude = $V_0 e^{-\beta l}$. Dotted-line curve V' shows instantaneous voltage when V_0 is a maximum, i.e. $V_0 e^{-\beta l} \cos \alpha l$.

The transmission of currents in a telephone line is analogous to the transmission of vibrations along a stretched cord. If we jerk one end of such a cord, we know that the disturbance will travel down the line in the form of a wave with a definite velocity depending on the mass and density of the rope. Similarly, if we suddenly impress an E.M.F. on the sending end of a long telephone cable, an electromagnetic wave will travel down the line with a velocity depending on the electrical characteristics of the cable, i.e. resistance, inductance, capacity and leakance. There is therefore an interval between the time of applying this E.M.F. and the time it affects a point some way down the line: the further away the point, the greater the time-lag. Now if the disturbing electromotive force, V_0, be of sine form, then the potential difference at any point (after a negligible interval when steady working conditions are reached) will also follow the sine law, but there will still be this time-lag between them. If we consider their vectors, the potential difference will lag behind V_0 by an angle which increases with the distance from the sending end. At a certain point the angle of lag will be 360 degrees = 2π radians, i.e. the potential difference is in phase with V_0; the distance from the sending end to

this point is the wave-length of the cable for the frequency considered. Where the angle $= 4\pi$ radians, the distance is 2 wave-lengths, and so on.

Returning to the case of the stretched cord, we know that the amplitude of the wave gradually diminishes as the vibration travels down the line. It loses energy in overcoming internal friction and the resistance of the air, and thus the motion is damped out. Similarly, the magnitude of the E.M.F. is attenuated as the electromagnetic wave travels down the cable, owing to the loss of energy, due to resistance and leakage. The amplitude diminishes with the length according to a logarithmic law:

$$V = V_0 e^{-\beta l}$$

where β is a constant representing the attenuating powers of the cable: β is therefore called the "attenuation constant" of the cable. To express fully the voltage at any point, we must also take account of the angle of lag, hence $V = V_0 e^{-\beta l} \angle \alpha l$, i.e. V lags behind V_0 by an angle αl, where α is a constant. Inasmuch as when $\alpha l = 2\pi$, l is the wave-length, or the wave-length $= 2\pi/l$, α is called the wave-length constant of the cable.

The evaluation of these important constants β and α in terms of the more familiar constants, R, L, G and C involves the solution of a differential equation. The results are as follows:—

$$\beta = \sqrt{\tfrac{1}{2}\left\{\sqrt{(G^2 + \omega^2 C^2)(R^2 + \omega^2 L^2)} + (GR - \omega^2 LC)\right\}}$$ per mile

$$\alpha = \sqrt{\tfrac{1}{2}\left\{\sqrt{(G^2 + \omega^2 C^2)(R^2 + \omega^2 L^2)} - (GR - \omega^2 LC)\right\}}$$ per mile

where R = resistance in ohms per mile;
L = inductance in henrys per mile;
G = leakance in mhos per mile; and
C = capacity in farads per mile, assumed uniformly distributed along the length of the cable;
ω = angular velocity in radians per second $= 2\pi f$, where f = frequency in periods per second.

The expression $V = V_0 e^{-\beta l} \angle \alpha l$ is true only if the cable is very long, for the transmitted wave is reflected when it reaches the far end and returns along the line, thus affecting the potential difference; but if the line is very long, then the reflected wave is so attenuated as to be negligible. In all cases, however, the expressions given for β and α are true, and these are of the greatest importance as they measure the speaking qualities of the cable.

Attenuation and Distortion.

We have three distinct effects to consider in the received current:—

(1) The diminution in volume of speech, which is given approximately by the factor $e^{-\beta l}$ for the mean speech frequency, i.e. $\omega = 5\,000$ radians per second.

(2) The relative attenuation of the different frequencies present in the voice, i.e. the distortion. If the attenuation for the higher frequencies is much greater than for the lower, then the received current will be deficient in these high harmonics and the voice will appear "drummy." This effect is so marked in certain cables that, although the volume is sufficient, the speech is so distorted as to be unrecognizable. To avoid distortion we must make β independent of the frequency as far as possible.

(3) The third consideration is the phase displacement of the different harmonics relative to the fundamental, i.e. the phase distortion. The extent to which this affects intelligibility of speech is somewhat uncertain. It has been stated that, providing the various harmonics are present in the received current in their correct proportions, their relative phase displacements are of minor importance.

Measurement of Distortion.

Distortion is conveniently measured by the rate of change of the attenuation constant with frequency. Actually, measurements are taken at the three frequencies, $\omega = 3\,000$, $5\,000$, and $7\,000$ radians per second, obtaining $\beta_{3\,000}$, $\beta_{5\,000}$ and $\beta_{7\,000}$ respectively. The distortion proper per 1 000 radians per second is $\frac{1}{4}(\beta_{7\,000} - \beta_{3\,000})$, but in order to compare different cables it is necessary to consider the distortion for the same attenuation, and hence one divides by the $\beta_{5\,000}$. The result is:—

$$\delta = \frac{\beta_{7\,000} - \beta_{3\,000}}{4\beta_{5\,000}} \times 100 \text{ per cent}$$

Improvement of Transmission.

To increase the volume of received current we must increase $e^{-\beta l}$, i.e. decrease β, and from the equation

$$\beta = \sqrt{\tfrac{1}{2}\left\{\sqrt{(G^2 + \omega^2 C^2)(R^2 + \omega^2 L^2)} + (GR - \omega^2 LC)\right\}}$$

one can deduce that there are three practical methods open:—

(*a*) To decrease the resistance R;
(*b*) To decrease the capacity C; and
(*c*) To increase the inductance L.

The first two methods were recognized and appreciated in the very early days of telephony, as they followed from submarine telegraph practice. A limit is reached, however, beyond which it is inadvisable to go, as decreasing the resistance involves increased diameter and cost of copper and hence of the gutta-percha (G.P.) insulation; it also involves increased weight and size of cable. The capacity $C = K/(\log_e D/d)$, where D = diameter over the dielectric, d = diameter over conductor, and K is the specific inductive capacity of the dielectric. It will be seen that, in order to decrease the capacity, D must be increased, which entails increased cost of gutta-percha and again an increase in the weight and size of the cable. Alternatively, one can use a dielectric possessing a lower value for K, e.g. paper, either solid or air-spaced. Cables have been constructed in which the paper has a coating of gutta-percha, but they were not successful as the paper absorbs moisture from the gutta-percha. A more successful type is one in which the paper is lead-cased; plugs

have to be inserted at frequent intervals so that, if a fault develops, the incoming water should not ruin the whole length of the cable. This form of construction, however, is bulky and heavy and is suitable principally for shallow water.

To the early electricians, increasing the inductance appeared to be equivalent to adding resistance to the circuit, and, if anything, the tendency was to eliminate inductance as far as possible. It was Heaviside who, by developing the mathematical theory of the telephone cable about 1887, first drew attention to the possibility of increasing the volume of speech by adding inductance to the line and so neutralizing its capacity. He also discussed the distortion produced, and showed that, for a distortionless line, β must be independent of frequency, and that this would be so if $R/L = G/C$.

intervals along its length, and he showed that, provided there were not less than π inductance coils per wavelength, the cable acts as regards attenuation as if the lumped inductance of the so-called "loading coils" were uniformly distributed along its length. The highest frequency it is desired to pass is in the neighbourhood of 2 000 periods per second, and hence we require at least π coils per wave-length at this frequency. This is equivalent to 9 coils per wave-length at 800 periods per second, and these figures have been confirmed by practical results.

The first application of loading was to land lines, and in this connection coil-loading has obvious advantages over continuous loading. However, submarine cables stand in far greater need of loading, owing to their inherently greater capacity and smaller inductance,

TABLE 1.

Coil-loaded Submarine Cables.

Title	Length	Date	Weight per Naut: Copper	Weight per Naut: Gutta-percha	R_1/L_1	G/C	Constants per Naut: Resistance, R	Inductance, L	Capacity, C	Attenuation Const., β	Z_0	Frequency at which Measured	Remarks
	nauts		lb.	lb.			ohms	mH	μF		vector ohms	~	
Anglo-French	20	1910	160	300	60	120	14·2	100	0·138	0·021	1 000	1 000	Phantom not loaded
Anglo-Belgian	47·9	1911	160	150	60	12	14·2	100	0·157	0·018	800	800	—
Isle of Wight	5	1913	160	150	48	20	14·2	100	0·159	0·015	—	800	—
Anglo-Irish	63·4	1913	160	150	48	15	14·2	100	0·166	0·015	690	800	—
Anglo-Dutch	85	1914	310	200	40	20	7·42	80	0·187	0·011	2· 40′ 647 0 55′	800	This cable was not laid as intended, owing to the war
Danish Govt.	22	1915	160	150	40	20	14·2	100	0·160	0·015	—	800	—
British Govt.	236 (in all)	1915 to 1918	—	—	40	20	—	—	—	—	—	800	Various types
Swedish Govt.	73	1920	350	212	40	20	6·4	80	0·187	0·0108	660	800	—
Danish Govt.	59	1920	110	100	40	20	20·6	80	0·156	0·021	3· 0′ 800	800	8 cores

The ratio G/C for gutta-percha is about 120, whereas R/L for an ordinary cable is of the order of 5 000 or more. Therefore, it is necessary to add inductance to diminish both attenuation and distortion.

LOADING OF SUBMARINE TELEPHONE CABLES.

There are two practicable means of increasing the natural inductance of cables; (*a*) by winding one or more layers of fine iron wire uniformly in a close spiral along the length of the conductor, and (*b*) by inserting at intervals a "lumped" inductance in the form of a coil of copper wire wound over an iron core. The first method suggests itself from the mathematical treatment of the problem, in which all the inductance is considered to be uniformly distributed. The second method was put forward by Professor Pupin in 1899. He considered the case to be analogous to that of the vibration of a stretched cord loaded with weights at

and consequently greater distortion as compared with aerial lines of equal attenuation. The insertion of loading coils along the length of a submarine cable is by no means an easy problem, and the first attempts at loading were made on the continuous method. The Danish engineer Krarup constructed a cable on this principle in 1902, and in the following 5 years a number of lengths were laid, chiefly around the coasts of Scandinavia. The first coil-loaded submarine cable to be constructed was laid across Lake Constance in 1906. The cable contained 14 cores, was paper-insulated and lead-cased, and the total length was 12 km. In 1909 the British and French Governments each agreed to lay a telephone cable between England and France. The British Post Office already had one, a 4-core unloaded type, and they eventually decided on a 4-core coil-loaded gutta-percha-covered cable for the new line, the French adopting the continuously loaded type.

The coil-loaded cable was constructed and laid by Messrs. Siemens Bros. and Co. in 1910,* and subsequently this firm manufactured a number of Pupin-loaded cables, the details of which are given in Table 1.

The coils in the Anglo-French cable were, for maintenance reasons, inserted every nautical mile, the total inductance being 100 mH per naut. The insertions at either end were placed at $\frac{1}{2}$ naut from the terminal apparatus, as this reduced reflection losses. Subsequent practice has been to retain 1 naut as the interval between coils, but recent cables have a lighter loading of 80 mH per naut.

Phantom Circuit.

In 1881–2 Mr. F. Jacob patented the method of using the two wires of a twin telegraph cable in parallel, the current returning through the earth; thus with two wires there are two circuits, the first having a metallic return and therefore being immune from outside disturbance, and the second, having the earth return, being the same as an ordinary single-core telegraph cable.

This principle was extended in telephony to obtain another circuit in addition to the two already provided by a 4-core cable. The connections for this phantom or superimposed circuit are shown in Fig. 2. Each end

Returning now to the loading coils, a moment's reflection will show that, in using the phantom circuit, the side-circuit coils will appear to possess no inductance, as there are two magnetic fields set up in the coil in opposite directions. It is possible to load the phantom by inserting another coil in each circuit, this coil being wound so that the magnetic fields aid each other when the currents in each half are in parallel. This method was first used on the Anglo-Belgian cable in 1911.

Losses in Loading Coils.

The gain in inductance due to the coils is not obtained without cost. In addition to the ohmic resistance of the windings, there is the extra loss with alternating currents due (1) to the eddy currents, which vary as the square of the frequency, and (2) to hysteresis in the iron, which varies directly as the frequency. In the coils of the Anglo-French cable the total resistance per coil was about 6 ohms at 800 periods per second, which gives a ratio

$$\frac{R_1}{L_1} = \frac{\text{added resistance}}{\text{added inductance}} = 60$$

Recent cables are loaded with the coil of improved type in which the value of R_1/L_1 is reduced to 40.

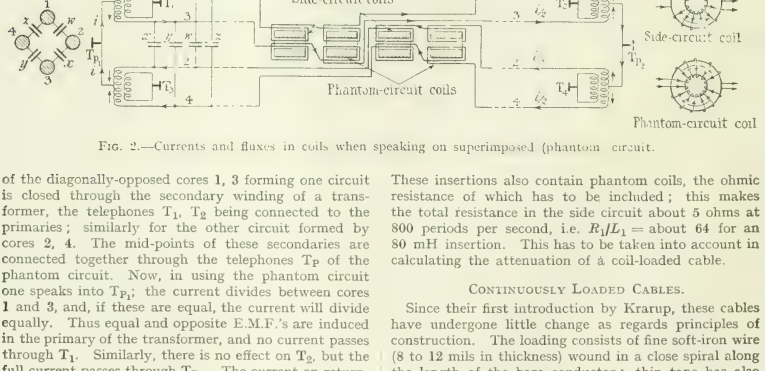

Fig. 2.—Currents and fluxes in coils when speaking on superimposed (phantom circuit.

of the diagonally-opposed cores 1, 3 forming one circuit is closed through the secondary winding of a transformer, the telephones T_1, T_2 being connected to the primaries; similarly for the other circuit formed by cores 2, 4. The mid-points of these secondaries are connected together through the telephones T_P of the phantom circuit. Now, in using the phantom circuit one speaks into T_{P_1}; the current divides between cores 1 and 3, and, if these are equal, the current will divide equally. Thus equal and opposite E.M.F.'s are induced in the primary of the transformer, and no current passes through T_1. Similarly, there is no effect on T_2, but the full current passes through T_{P_2}. The current on returning divides equally between cores 2 and 4, these being equal, and so does not affect T_3 and T_4.

In a similar manner, it is clear that in speaking from T_1 to T_2 through the side circuit 1–3, the E.M.F. tending to send a current in one direction through the superimposed circuit is balanced by an equal E.M.F. tending to send a current in the opposite direction. No sound, therefore, occurs in the telephones T_P.

These insertions also contain phantom coils, the ohmic resistance of which has to be included; this makes the total resistance in the side circuit about 5 ohms at 800 periods per second, i.e. R_1/L_1 = about 64 for an 80 mH insertion. This has to be taken into account in calculating the attenuation of a coil-loaded cable.

Continuously Loaded Cables.

Since their first introduction by Krarup, these cables have undergone little change as regards principles of construction. The loading consists of fine soft-iron wire (8 to 12 mils in thickness) wound in a close spiral along the length of the bare conductor; thin tape has also been used for the purpose. There may be a number of layers of iron, not exceeding three, depending on the degree of loading required. The copper conductor is usually in the form of a solid central core, the outer strands being flat tapes, which gives a smaller conductor for the weight, and therefore requires less iron to cover it. The loaded copper is covered with gutta-percha in the usual way, and served, laid up and sheathed as an ordinary cable. The construction therefore entails no extra difficulties. Some of the earlier Continental

* W. A. J. O'Meara: "Submarine Cables for Long-distance Telephone Circuits," *Journal I.E.E.*, 1911, vol. 46, p. 309.

cables were made with paper insulation and were lead-cased, instead of being covered with gutta-percha.

The increased size of the conductor with its iron coat means a greater capacity per naut as compared with a coil-loaded cable of the same size. Further, it is not possible to obtain economically the same high degree of loading as with the coils. For instance, using three layers of 0·008 inch iron on a conductor weighing 150 lb. per naut (single), the inductance would be about 24 mH per naut loop, as compared with the 80 or 100 mH obtained in a lump-loaded cable. Also, the extra resistance due to losses in the iron per millihenry of added inductance is higher in the continuously loaded cable as usually made. The ratio R_1/L_1 varies with the size of the conductor; for the 150-lb. cable quoted above, it would be about 70 to 75. A detailed comparison of the two methods of loading was given in a paper* by J. G. Hill, and the conclusion he drew was that, to obtain a given attenuation constant, the coil-loaded cable is cheaper to construct. Table 2 gives a list, with some particulars, of continuously loaded cables.

Calculation of the Attenuation Constant β.

In the case of a loaded cable, the lengthy expressions for β and α given above reduce to the following:—

$$\beta = \frac{R}{2}\sqrt{\frac{G}{C}}\sqrt{\frac{C}{L}}$$

$$\alpha = \omega\sqrt{LC}$$

provided that $(R/\omega L)^2$ is small compared with unity. It will be noticed that this expression for β is independent of frequency, and, therefore, if the so-called constants were really constant for the different frequencies, the distortion would be zero. This, however, is not the case, as in a loaded cable the iron loss, and therefore the resistance R, vary with frequency; further, the ratio G/C also varies with the frequency.

This form of the expression for the attenuation constant β shows another method of decreasing β, viz. by decreasing the ratio G/C. This has been done in a form of special gutta-percha-covered cable manufactured by Messrs. Siemens Bros. and Co. in which G/C is reduced from 120 to 20 at $\omega = 5\,000$.

Comparison of Different Types of Cable.

To recapitulate, we shall consider some figures of different forms of line, showing how the variation in the line constants affects their transmission qualities. It is sometimes convenient to refer to the attenuation in terms of that of some standard cable; the P.O. standard cable is therefore given at the head of the list, and the others are compared with it.

Limits of Transmission.

The general standard of the British Post Office for long-distance communication between stations in Great Britain and Ireland is that the audibility should not be worse than over 35 miles of standard cable (m.s.c.), i.e. a figure for βl of 3·7. Allowing 10 m.s.c. for the local lines, we get 25 m.s.c. ($\beta l = 2{\cdot}65$) for the transmission line proper, and the lengths to give this attenuation are worked out in Table 3 for the different cases.

Cross-talk and Overhearing.

It might very well be asked why the length of the cable should not be increased by increasing the sending current, so that however great the βl value of the cable, i.e. however much this current were attenuated, there would still be sufficient arriving at the far end to affect the receiver. The objections are (1) distortion, which we have already considered, and (2) cross-talk and overhearing. Cross-talk is the inductive interference (magnetic or electrostatic) between two separate circuits; while overhearing is the interference between side and superimposed circuits.

Consider the four wires 1, 2, 3 and 4 in Fig. 2. There will be a certain capacity (w) between 1 and 2, and between 1 and 4 (z). Consequently, when a current flows in core 1 it will induce currents in cores 2 and 4. These currents are opposite in direction, and will neutralize each other if the capacities w and z are equal; similarly for the influence of the other core 3 on cores 2 and 4. But if these capacities are not quite equal, due, for example, to the conductors being slightly eccentric in the gutta-percha cable, then there will be a small current induced in circuit 2–4, when speaking on 1–3. This causes cross-talk, a similar reasoning applying to magnetic interference.

In considering the action of the phantom circuit, we supposed that cores 1 and 3 are equal, and consequently no current flowed in the telephone T_1 when speaking in T_P. But if the cores have any inequality in resistance, inductance, capacity or leakance, then there will be a small current in T_1 which will cause overhearing. Similarly, due to this inequality, overhearing will occur on the phantom in speaking on the side circuit.

A recent British Post Office specification required that the cross-talk between side circuits should not exceed 200 millionths of the speech current. Accepting this figure, we see that the effect on the adjacent circuits is equivalent to a received current attenuated to 200 millionths of its initial value, which is equivalent to 80 miles of standard cable. Therefore, if we had a line of that attenuating power, say from England to Scandinavia, and two conversations were going on over two separate circuits, those in England would hear each other speaking as loudly as they would hear the people in Denmark. This interference would make simultaneous conversation impossible, and is not to be overcome by increasing the current. The only thing to do is to decrease the attenuating power of the cable.

Overhearing is more serious than cross-talk, especially with coil-loaded cables. In these, the value of 2 000–4 000 millionths of speech current is obtained for the overhearing, although the halves of the loading coils are carefully balanced. The same trouble is experienced on land lines, and trunk mains are now accurately balanced up between loading coils to overcome the difficulty. It is impossible, however, to balance a submarine cable to the same extent as a multiple-twin

* "A Comparison between Coil-loaded and Continuously Loaded Cables," *Electrical Review*, 1912, vol. 71, pp. 892, 931 and 973.

TABLE 2.

Continuously Loaded Submarine Cables.

Title	Date	Length	No. of Cores	Weight per Naut		No. of Loading Wire and Size in Mils	G / C	Per Nautical Mile Loop					Z_0	Frequency	Remarks
				Copper	Dielectric			R_0	R (Effective)	L	C	β			
		nauts		lb.	lb.			ohms	ohms	mH	μF		vector ohms (260)	∿	
Elsinore-Helsingborg	1902	2·85	4	(127)	(191)	1×7·87		16·98	17·58	9·84	0·152	0·0340	(8° 46′) (267)	900	—
Fehmarn-Laaland No. 1	1902	10·38	4	(364)	—	1×11·81		6·36	9·58	9·30	0·133	0·0184	(5° 10′) (497)	900	Impregnated paper, lead-sheathed
Greetsiel-Borkum	1903	15·85	4	(127)	—	1×11·81	—	18·06	22·16	14·82	(0·062)	0·0225	(7° 24′) 328	900	Air-space paper, lead-sheathed
Cuxhaven-Helgoland	1903	40·50	2	2·42	(437)	—	1×11·81	—	5·06	6·76	7·96	(0·075)	0·0104	4° 16′ (270)	900	Solid paper, lead-sheathed
Seeland-sause-Jutland	1904	8·03	4	285	(195)	3×7·87		7·96	8·36	16·16	0·223	0·0156	(2° 37′) (271)	900	—
Korsor-Nyborg	1906	10·30	8	(285)	(195)	3×7·87	—	7·98	8·65	17·3	0·237	0·0199	(2° 58′)	796	—
Along coast of Iceland	1907	—	2	(182)	(159)	1×19·7	—	—	—	—	—	—	—	—	—
Fehmarn-Laaland No. 2	1907	10·41	4	(262)		3×7·87	—	8·92	—	18·2	0·077	0·0124	— (250)	796	Air-space paper, lead-sheathed
Elba-Piombino	1909	7·10	4	101	116	1×7·87	—	22·45	24·88	9·76	0·169	0·0492	(11° 3′) (278)	1,000	—
French P.O. Channel	1911	23·42	4	300	(300)	1 12·0	110	(7·75)	8·53	13·5	0·176	0·0184	(2° 33′) 302	1,000	—
Adriatic	1913	31·80	4	210	(180)	3×7·87	94	11·0	(12·6)	19·8	0·216	0·0242	2° 45′ 250	800	—
Vancouver-Victoria	1913	28·30	4	300	300	1 12·0	70	8·0	9·16	11·56	0·175	0·0194	4° 30′ 363	800	—
Norwegian Government	1920	About 230 in all	2	155	180	3×8·0	20	14·92	16·53	23·23	0·185	0·0123	3° 30′	796	Special gutta-percha

Figures in brackets are calculated and approximate.

The figures for the effective resistance R are not strictly comparable in the earlier cables, as the methods of measurement were doubtful and the strength of the current used is not given.

TABLE 3.

Comparison of Different Types of Cable, showing Effect of Varying Line Constants.

Type	Loading	Total Effective Resistance, R	Inductance	Capacity, C	Leakance, G / C	Characteristic Impedance, Z_0	Wavelength Constant, α	Wavelength, $2\pi/\alpha$	Attenuation Constant, β	Standard Cable Equivalent	Length to give 25 m.c. ($\beta L = 0{\cdot}163$)	Distortion	Remarks
		ohms	mH	μF	micro-mhos	vector ohms		miles		miles	miles	per cent	
Standard cable, underground A.S.P.C. *	Nil	88	1·0	0·054	1	43° 16′ 198	0·1119	56	0·1062	1·0	25	9·5	R large C small
150-lb. underground A.S.P.C.	Nil	11·73	1·0	0·065	1	15° 4′ 33° 22′ 725	0·0537	117	0·0356	0·335	74·5	5·5	R small C small
150-lb. aerial wire	Nil	11·73	3·76	0·0084	1	15° 16′ 153	0·0292	215	0·00874	0·082	304	2·6	Small distortion
150-lb. per st. ml. submarine cable†	Nil	11·73	1·25	0·15	18	30° 15′ 685	0·0851	74	0·0525	0·494	50·5	6·0	C large R small
150-lb. per st. ml. submarine cable	Coils 80 mH per naut	16·08	70	0·15‡	18	120	0·36° 685	0·513	12·2	0·0179	0·169	148	11·6	R increased $G/C = 120$
150-lb. per st. ml. submarine cable	Coils 80 mH per naut	16·08	70	0·15‡	3	20	1° 12′ 343	0·513	12·2	0·0127	0·120	208	5·0	Special gutta-percha $G/C = 20$
150-lb. per st. ml. submarine cable	Continuous, 3 layers 0·008 inch iron	13·21	21	0·18	3·6	20	3° 30′	0·308	20·4	0·0199	0·188	133	5·0	R increased C increased

For the purposes of comparison, all figures are given per statute mile and are effective values at 796 periods per second, i.e. $\omega = 5\,000$.

* Air-space paper-covered. † Illustrated in Fig. 1. ‡ The small increase in capacity due to coils is neglected.

trunk main, owing first to the higher capacities involved, and secondly, to the very limited choice in the ways of connecting the cores.

Continuously loaded cables are freer from overhearing than those loaded with coils. It is possible, by using all four cores in parallel with earth return, to obtain a "super-phantom" circuit on a 4-core continuously loaded cable, and the Anglo-French and British Colombia cables therefore give four circuits, i.e. two sides, one phantom, and one super-phantom. The overhearing on coil-loaded cables is so bad, however, as to render the use of the super-phantom impracticable on them.

Telephonic Repeaters.

An obvious method of increasing the transmission length is to use relays, as is done in telegraphy. A telephone relay has to be robust and yet sensitive to

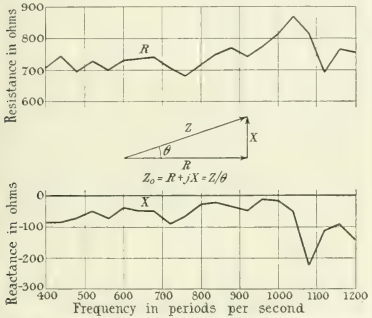

Fig. 3.—Variation of characteristic impedance with frequency on a coil-loaded submarine cable.

minute currents, to respond to frequencies of at least 2 000 periods per second, and to magnify all frequencies to the same extent. Mechanical devices obtained only a partial success, but the thermionic valve has provided an almost ideal telephone relay.

The explanation of the action of the thermionic valve acting as an amplifier is given in any modern book on wireless telegraphy and so will not be gone into here. An essential of any repeater circuit is that it must not react on itself—otherwise the various frequencies are unequally amplified and so the speech is distorted; or the valve circuit may even oscillate and give a singing note which will interfere with the transmission. It has been found that, with the arrangements in use at present, one condition for perfect action is that the impedance of the line must be the same in both directions, and for all frequencies. This is difficult to realize in practice, so each side is balanced by an artificial line, which consists of an arrangement of resistance and condensers. It is in this way possible to amplify between two lines possessing quite different characteristics, e.g. an aerial line and a submarine cable.

It is possible to construct artificial lines which match very closely any cable for all frequencies, provided that the impedance varies regularly with the frequency. Any discontinuity or irregularity in the cable, however, shows up in the impedance/frequency curve, and it is not possible to obtain a good balance. A coil-loaded cable is really discontinuous and, if the coils are not exactly equidistant and equal in inductance, the impedance varies considerably. A typical curve for a coil-loaded submarine cable is shown in Fig. 3. It will be seen that the variation in the resistance component is about 12 per cent, while the variation in the reactance component is equivalent to a change of 5 degrees in the vector angle.

Continuously loaded cables give a much smoother curve. For one cable tested, in which no more than usual care had been taken to obtain uniformity, the corresponding figures were 5 per cent variation of R and $3\frac{1}{2}$ degrees variation of angle; such cables can be made to give even better figures if sufficient care is taken in manufacture. They are therefore much more suitable for working with relays than are coil-loaded cables, and this will probably prove the deciding factor in their favour.

Comparison of Coil-loading and Continuous-loading Methods.

We are now in a position to compare the two methods of loading.

In favour of coil-loading.

(1) Enables the use of a smaller conductor and less gutta-percha for the same attenuation constant, and therefore reduces the first cost of the cable.

(2) It is possible to add inductance up to any amount, and thus obtain less attenuation. This has not been so important since the introduction of amplifiers.

(3) The ageing of the iron does not unbalance the circuits.

In favour of continuous loading.

(1) Simplicity of construction.

(2) Cable can be laid and repaired like an ordinary gutta-percha telegraphic cable.

(3) Has fewer joints and is not liable to faults at loading coils, and therefore gives cheaper maintenance.

(4) Faults can be located more easily by resistance measurements.

(5) Known to be reliable at the greatest depths of water.

(6) Overhearing is less, and four circuits can be obtained from a 4-core cable.

(7) The characteristic impedance is more suitable for use with amplifiers.

(8) Short lengths unavoidably added in repair do not affect the smoothness of the impedance curve.

The balance of advantages is on the side of the continuously loaded cable, and it is doubtful whether any more coil-loaded cables will be made in the future.

Improvement Obtained by the Use of Amplifiers.

A double-relay repeater gives an improvement equal to 15–25 miles of standard cable, and, by the use of successive repeater stations, good speech is now possible between New York and San Francisco, a distance of about 3 000 miles. The introduction of repeaters brings into possibility conversation between England and remoter parts of Europe, but the limits of distortion and cross-talk on a long submarine cable still remain. Consequently, speech across the Atlantic is not yet possible, even with amplifiers at the sending and receiving ends.

The author desires to acknowledge the kindness of Messrs. Siemens Brothers and Co. in permitting him to make use of the particulars of their coil-loaded and continuously loaded cables, also his indebtedness to "The Theory of the Submarine Telegraph and Telephone Cable," by H. W. Malcolm, for some of the information in Table 2.

RADIO-TELEGRAPHIC TRANSMITTERS.

By A. C. Warren, B.Sc. (Eng.), Student.

(Abstract *of paper read before the* Students' Section, *29th April*, 1921.)

Summary.

This paper deals only with the generation of high-frequency currents and the means of controlling them. A few particular features of interest are described rather than general descriptions. The paper is divided into five sections :—

(1) *Spark transmitters.*—The Timed Spark system as employed at Carnarvon and Stavanger is described.

(2) *The Poulsen arc.*—A short description of the underlying theory is given. The practical construction of an arc set is described, together with the means of controlling it.

(3) *The high-frequency alternator.*—The lay-out of the Lyons station is described and the precautions taken to obtain constant speed are indicated.

(4) *Valve transmitters.*—The valve is still in the first stages of development as a means of generating high-frequency currents for large powers, but the circuits employed are almost fully developed. Circuits are described and figures given for the larger types of valve and for transmitting circuits.

(5) *Conclusion and future developments.*

(1) Spark Transmitters.

A wide field still remains to the spark set in ship working, but, in this, only small power sets are used and for point-to-point working very few high-power spark sets are now employed. Perhaps the most important of these are the timed spark sets at Carnarvon and Stavanger.

The timed spark system.—In the ordinary spark system the wave-train due to each spark lasts about the $\frac{1}{10\,000}$th part of a second and the time between sparks is about $\frac{1}{500}$th of a second. Thus a considerable time elapses between wave-trains. If, however, each train of oscillations were to be started before the previous train had died out and in such a way that the two sets of oscillations were in phase, then a continuous but fluctuating oscillation would be generated in the aerial. This is the underlying principle of the system.

Fig. 1 gives a skeleton diagram of the arrangement. Current is supplied from high-tension direct-current machines to the condensers C_1, C_2, C_1, across each of which is shunted a tuning inductance and spark-gap in series. The spark-gaps in the form of discharger discs are mounted on a separately-driven shaft, two main discs and one triggering disc. The trigger disc

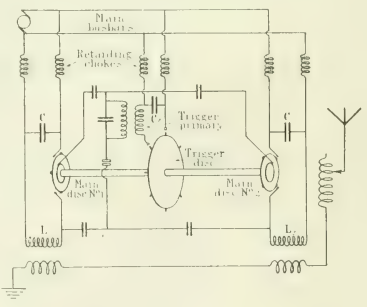

Fig. 1.

has twice as many spokes as each of the main discs, and a main disc comes into the spark position each time the trigger disc sparks, the main discs thus coming into the sparking position alternately.

The gaps are so adjusted that the trigger circuit will spark with the busbar voltage; the main circuits, however, require an excess of volts above this to cause them to bridge their gaps. When a spark occurs at the trigger disc oscillations are set up in the trigger

primary and secondary, the latter being shunted across one half of each main gap. The electromotive force induced in the trigger secondary breaks down one half of either No. 1 or No. 2 main gap, and the busbar voltage is sufficient to break the other half, thus setting up oscillations in the main circuits which are coupled to the aerial.

The following figures apply to the installation at Carnarvon :—

Generators. 500 kW at 10 000 volts (2 generators each giving 5 000 volts).
Discs. 50 inches diameter, trigger disc 48 spokes, main discs 24 spokes each. The discs are run at 1 950 r.p.m. and require 60 kW to drive them.
Spark-gaps. Main gaps $\frac{1}{3}$ in., trigger gap 1/100 in., air blast 20 lb. per sq. in. requiring 15–20 kW.
Wave-length. 14 000 metres; a spark consequently occurs about every 14 oscillations.
Aerial current up to 300 amperes is obtained and an overall efficiency of 40 per cent.

This system has given good results; the phasing arrangements, however, are difficult to adjust correctly in practice, and the advent of the generator of pure continuous waves has rendered the manufacture of further sets unlikely.

(2) Arc Generators.

The generation of audio-frequency currents by means of the arc was discovered by Duddell, but the improvements necessary before oscillations of radio-telegraphic frequency could be generated were due to Poulsen. These improvements were :

(*a*) Burning the arc in a hydrogenous atmosphere, thus giving a steeper arc characteristic and rapid de-ionization.
(*b*) The introduction of a magnetic field for blowing out the arc.
(*c*) The use of a copper water-cooled anode and carbon cathode, the latter capable of being rotated slowly in order to keep the arc burning evenly.

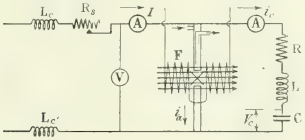

Fig. 2.

Fig. 2 indicates the diagram of connections of an arc generator, and in Fig. 3 the curve shows the arc voltage and current cycle. L_c, L_{c1}, are high-frequency chokes tending to keep the main feeding current constant.

It is assumed that the main feeding current I is constant and that the condenser C is fully charged in a negative direction at the commencement of the cycle, its voltage following a sine-wave variation throughout the cycle. At this instant the condenser current i_c is zero, and thus the arc current i_a is equal to the constant feeding current I.

As the condenser discharges it receives a positive current i_c and the arc will be extinguished when $i_c = I$. Meanwhile the arc voltage v_a has been increasing, due to the decrease of i_a until the arc is extinguished, when it drops to the value $v_a = v_c + RI$. If v_c is negative and greater than RI, v_a becomes negative. From this point the voltage on the condenser continues to rise, v_a following parallel with this until it is sufficient to strike the arc again. The condenser current then decreases from this point, following a sine-wave variation and leading 90° on the condenser voltage throughout the remainder of the cycle.

The effective power delivered into the oscillatory circuit is the integrated product of v_a and i_c. Between the points D and E this is negative and thus, for a big oscillatory power, the feeding current, the extinction and ignition voltages, and the oscillatory circuit resistance should be large, whilst the arc potential difference (v_a) between D and E should be small.

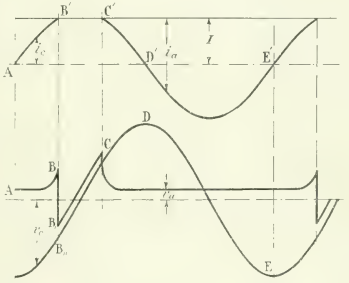

Fig. 3.

For large extinction and ignition voltages a long well-deionized arc is necessary, whilst for a small "heavy current" arc potential difference a short arc length is required. The latter is the more important factor in the case and therefore takes precedence.

Practical details.—Arcs are constructed in sizes varying from 1 to 1 000 kW, a 350-kW set being capable of delivering 300 to 350 amperes into the aerial. The arc is supplied from d.c. mains at 220 volts for sizes up to 5 kW, and at 800 to 1 200 volts for 250–350 kW sets. Current is supplied to the arc through the high-frequency chokes L_c (Fig. 2), the starting resistance R_s (cut out when the arc has been struck and the length roughly adjusted) and the field-magnet coils F. The aerial circuit indicated by RLC is shunted across the arc.

Arc chamber.—This is of gunmetal with a water-cooling jacket and a removable lid giving easy access

to the interior for cleaning purposes. A safety valve is fitted to the lid and is adjusted to lift at about 5 lb. per sq. in. (If the chamber is leaky an explosion may occur on striking the arc, due to the presence of an air-hydrogen mixture.)

The pole-tips pass through holes in the sides and the anode and cathode through the back and front respectively. The whole is rendered air-tight by suitable asbestos packing.

Electrodes.—The copper anode is tubular with a narrow, solid replaceable tip. It is water-cooled and is rigidly fixed to an ebonite face-plate supported by four steel studs screwed into the arc chamber. A porcelain or silica collar acts as insulation and distance-piece between the chamber and face-plate and the joints between the chamber and face-plate, and those between face-plate anode collar and chamber are rendered air-tight by asbestos washers.

The anode and cathode vary from $1\frac{1}{4}$ in. to $2\frac{1}{2}$ in. diameter according to the size of the arc. The carbon cathode is held in a brass holder which is a working fit in the cathode sheath, the latter being bolted to the front face-plate and supported in the same way as the anode. The cathode sheath is slowly rotated by means of a small motor connected to it by a worm-driven reducing gear. The carbon holder may be slowly fed forward against the pressure of a spring by means of a screw-handle adjustment. In the head of the handle is a striking button by which the carbon may be momentarily pressed forward into contact with the anode.

The life of anode tips is roughly one month and the life of the cathodes one or two days' continuous working.

Magnetic circuit.—The yoke is of malleable cast-iron, to which the pole-pieces are fitted. In medium- and large-power sets the field coils are wound with bare copper strips, up to $2\frac{1}{2}$ in. $\times \frac{1}{8}$ in., interleaved with insulating material. The coils are wound spirally, tappings being brought out from each layer.

Hydrogen or alcohol feed.—Coal gas is used if a supply is available; otherwise alcohol is employed. A drip feed is employed and, in small sizes, vaporization is obtained by feeding the alcohol on to the hot electrodes. In large sizes an electric vaporizer is fitted; this facilitates rapid starting up and steady working of the arc.

Arc control.—In small and medium powers the control is by drum controller. This is in two portions—the first for auxiliaries, the second for the starting resistance. The auxiliary notches are: Alcohol feed-water circulation, Carbon drive motor, and Aerial send-receive switch. The supply is then switched on through the full starting resistance, the arc struck and adjusted, and the remaining resistance is then cut out. In large-power sets the arc is operated by remote control, the auxiliaries being operated by separate switches.

Keying arrangements.—The arc suffers from the disadvantages that it cannot be extinguished during signalling and that the oscillatory circuit must not be broken; oscillations must, therefore, be generated continuously during the whole period of transmission. Two methods of keying which comply with these conditions have been developed, namely, the "spacing and marking wave" and back shunt methods. The former consists in feeding the aerial all the time and varying the wave-length a few per cent for marking by short-circuiting one or two turns of the aerial inductance. In the latter method an auxiliary tuned circuit, tuned to roughly the same wave-length as, and with a resistance equal to, that of the aerial circuit, is substituted for the aerial circuit during spacing. Thus from marking to spacing the aerial circuit is cut off and the back shunt circuit is made. In order to ensure that one circuit is always across the arc, the circuit to be made is actually closed before the other circuit is broken.

Only the "spacing and marking wave" method is used for large-power sets, and then the change in wave-length is effected by short-circuiting a coil coupled to a portion of the aerial inductance. The inductance to be short-circuited is divided into sections, thus reducing the current broken at any section. Electro-magnetic keys with air blasts are used, and for high-speed working Creed engines are employed. An efficiency of 30 to 40 per cent is claimed, but it is believed that in many cases it is considerably lower.

(3) The High-frequency Alternator.

In 1890 Tesla produced an alternator capable of developing 1 kW at 10 000–12 000 periods per sec., but it was not until 20 years later that a practical high-frequency alternator was constructed. Alexanderson, Goldschmidt, Latour, Bethenod and others have now produced efficient high-power machines up to 100 000 periods per second.

In this case the transmitting wave-length is dependent, not on the constants of the circuits but upon the speed of rotation of the alternator and its construction. The maintenance of constant and high speed entails the use of much auxiliary apparatus, but even with this complication overall efficiencies of 40 to 50 per cent are obtainable.

Lay-out of the Lyons alternator set.—The high-frequency alternator set at Lyons is of the Bethenod-Latour type running at 3 000 r.p.m. and developing from 150 to 200 kW.

To ensure constant speed a special generating unit is installed to supply the driving motor of the alternator unit. Current is supplied to a three-phase induction motor, working on 3 000 volts, 50 periods per sec., which drives a d.c. generator giving 500 volts kept constant by means of a Thury field regulator. This generator supplies the motor which drives the high-frequency alternator unit, the speed of the latter being kept constant by a second field regulator.

The alternator has four windings, each giving 500 volts at 20 000 periods per sec. which are connected across the primaries of four air-cored transformers; the secondaries of these transformers are connected series-parallel to the aerial and earth. The gap between stator and rotor is only 0·7 mm, and in order to reduce windage losses the machine is run in a vacuum at a pressure of 5–10 cm of mercury. The rotor and stator are both oil-cooled, and all air is removed from this oil since air bubbles provoke vibration of the rotor. The oil is pumped through the stator, rotor and shaft back to the containers where the air is extracted and

the oil cooled. About 5–10 kW is absorbed in the oil pump. A small pump is geared to the alternator shaft for lubricating the bearings, and a hand pump is provided for lubrication during the starting period.

Owing to the very small gap between stator and rotor any vibration may become very dangerous. Vibration is affected by: (1) running in vacuo during starting; (2) the temperature of the cooling oil. It is found more difficult to start up if the oil is cold, and so the oil cooling is not brought into play until the machine has run up to speed.

The overall efficiency, including auxiliaries, is about 40 per cent and the installation is capable of putting 300 amperes into an aerial of 2 ohms' resistance. Keying is effected by magnetic keys across each generator winding; these short-circuit the winding during spacing and put the transformer primaries across the windings on marking. The internal impedance of the windings is great and so the spacing current is considerably less than the marking current; hence the power consumed during spacing is small (about $\frac{1}{4}$ full load).

(4) Valve Transmitters.

Valves of the two- and three-electrode types are now well established as current rectifier and generator of oscillations respectively. Their development for high-power transmission is still in an early stage, but their utility for low- and medium-power sets is great. A schedule is given below of some of the large types of glass valve in use.

Rectifying.

U.2. 500 watts, 0·55 ampere saturation current.
Filament: 18 volts, 5·4 amperes.
Anode: cylindrical $3\frac{1}{2}$ in. × $1\frac{1}{2}$ in. diameter.
Bulb: 12 in. × 6 in. diameter.

M.R.2. 1 kW.
Filament: 20 volts, 6 amperes.
Anode: cylindrical $3\frac{1}{2}$ in. × $2\frac{1}{2}$ in. diameter.
Bulb: 14 in. × 7 in. diameter.

Transmitting.

T.4.A. 500 watts, 0·34 ampere saturation current.
Filament: 18 volts, 5·4 amperes.
Anode voltage: 3 000–7 000 volts.
Of the same general construction as *U.2.*

M.T.4. 400 watts.
Filament: 18–19 volts, 6 amperes.
Anode: 2 500–6 000 volts.

The above valves are manufactured by the Marconi-Osram Valve Co. Valves of similar sizes are manufactured by the Mullard Radio Valve Co. and the Edison Swan Electric Co.

The rating of a valve is based upon the heat which the anode is capable of dissipating without becoming dangerously heated. By suitably designing the transmitting circuits a valve efficiency of 70–75 per cent is obtainable and thus a 500-watt valve can give an output of 1 to $1\frac{1}{2}$ kW into the aerial.

A silica valve capable of dissipating $2\frac{1}{2}$ kW and of delivering 35–40 amperes to a 3-ohm aerial has been designed and is in regular working. The future may see a 100-kW valve with metal container in use involving a water-cooled anode and continuous exhaustion of the valve during working.

Transmitting circuits.—A diagram is given in Fig. 4 of one of the transmitting circuits in general use. Power is supplied from the alternator A to the transformers T_1 and T_2. T_1 supplies the high-tension feeding current to the rectifier anodes, and T_2 the low-tension feeding current for the filaments. The transformer T_2 is of special construction in having two secondaries, one of these being highly insulated from the remainder of the transformer. This latter secondary supplies the rectifying valve filaments which are at a high potential above earth; the other secondary supplies the oscillating valve filaments. The iron-cored choke coils L_1, L_2, L_3, L_4, serve to regulate the voltage across the main transformer and the filament voltages.

The smoothing condenser C is inserted across the rectified supply which is taken through the high-frequency choke coil L_5 to the anode of the oscillating valve. From the anode connection is made through a blocking condenser C_2 to a tapping on the aerial inductance coil. The aerial is also tapped on to this coil, the tapping depending upon the wave-length

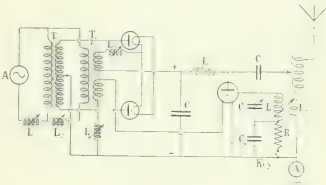

Fig. 4.

required. The earth is connected through an aerial ammeter to the other end of the aerial inductance, to the negative of the oscillating valve filament and to the negative supply lead.

Coupling is made to the grid through the anode and grid coupling coils L_6 and L_7, one end of L_7 being connected to the grid of the oscillating valve and the other through a condenser C_4 and leak resistance R_1, in parallel, to the negative of the filament. The condenser and leak ensure the steady negative potential on the grid of the valve and, since this will be dependent on the grid current flowing, the value of this potential will automatically adjust itself to the working conditions.

A variable condenser C_3 may be shunted across the grid coupling coil L_7, its function being to bring the oscillations on the grid exactly 180 degrees out of phase with those on the anode, thereby improving the efficiency.

The adjustment of valve sets for maximum efficiency is very critical. For efficient work the best value of anode tap and grid to anode coupling and also the correct phase compensation must be determined. The size of each piece of apparatus in the circuit varies according to the power, wave-length, aerial and type

of valve used. Below are given figures for a 1½ kW set:—

T_1 350–10 000 V.	A 600–3 000 metres.
T_2 350–20 V.	L_5 50–80 millihenrys.
C_1 0·5 μF, 10 000 V.	L_6 20 microhenrys.
C_2 0·005 μF, 10 000 V.	L_7 500–3 000 microhenrys
C_3 2 000 $\mu\mu$F (max.).	R 20 000–60 000 ohms.
C_4 0·005 μF.	

Aerial current: 10–15 amperes.

Valves: Rectifying, two U.1; Transmitting, one T.4.A.

For small- and medium-power sets the key is usually inserted in the grid leak circuit. The action of keying in the grid leak circuit is novel: If the grid leak is suddenly broken each pulse of grid current will charge the condenser C_4, making the grid further negative with regard to the filament and causing oscillations to cease. Keying in this circuit permits the key to be inserted direct and the current broken is only 10–20 milliamperes. For medium- and large-power sets keying is done by the simultaneous operation of keys in the main transformer circuit, high-tension feeding circuit and, sometimes, in the grid leak circuit also.

At present for sets delivering more than 1 kW to the aerial several valves are used in parallel. Two-, three-, and six-phase arrangements are also being investigated.

The use of a number of valves in parallel is naturally undesirable, and a great deal of research is being carried out in developing a high-power valve.

The overall efficiency of valve sets can be as high as 50 per cent, and this, combined with the fact that no spacing wave is necessary, is likely to bring the valve into high favour.

For powers up to 3 kW no power except filament watts is consumed during spacing, but above this it is found desirable to keep the set oscillating feebly during spacing. This gives signals a good clear note and prevents their becoming "clicky."

Conclusion.

The efficiencies of the various types of transmitter are given below:

Arc. 30–40 per cent (not including power plant but including auxiliaries).
Alternator. 35–50 per cent (overall).
Valve. 40–50 per cent (overall).

The actual figures vary according to the size, the efficiency increasing with the power.

For small-power work (up to 15 kW) the valve takes first place, owing to ease of manipulation, higher efficiency, and the fact that practically no load is taken during spacing. The capital cost for arc or valve sets is about the same and maintenance is of the same order. From the reception point of view the valve gives a good, clear note and has relatively few strong harmonics; the arc, on the other hand, has a bubbly note and strong harmonics.

For high-power work the only two serious competitors at present are the arc and the alternator. The alternator has the higher efficiency, but to balance this its capital cost and maintenance are higher than those of the arc. The arc has to carry full load in the aerial during spacing, and until this is remedied it will be a strong point against it. The deciding factor in the case, however, will be: Which causes the least interference? The alternator gives a pure note with very few harmonics, while the arc as mentioned above is liable to have a variable bubbly note and many harmonics, causing a great amount of interference.

The French in their plans for the Paris Radio-electric Centre have decided upon the installation of alternators, whereas at Bordeaux, Leafield, and Cairo arcs have been installed.

The Imperial Wireless Telegraphy Commission has, however, advanced further and has decided in favour of the high-power valve set.

Future developments.—The efficiency of the transmitter does not end at the generator. The aerial is the unit to which least attention has been devoted in the past. A common efficiency is 5–10 per cent, which leaves very much room for improvement. Multiple, tuned aerials have now been developed in America with a total resistance of 0·5 ohm and a radiation resistance of 0·2 ohm. In this country, counterpoise earths are in use having a resistance of 0·7 ohm and a radiation resistance of 0·25 ohm. This increase in efficiency is reflected on to the size of generator necessary, decreasing the power necessary and thus improving the position of the valve as a high-power generator.

Much improvement is necessary to make wireless telegraphy thoroughly commercial and capable of competing seriously with wire telegraphy for short as well as for long ranges. It is essential that duplex working at high speeds should be attained. Remote centralized control at speeds up to 100 words per minute duplex is being employed by the British Post Office and the same system is proposed for the Paris Radio-electric Centre.

Perhaps the biggest difficulty ahead is the cutting out of interference, atmospherics and other disturbances. Unless this can be solved at the receiving end, the range for a given power, and the utility of wireless telegraphy, will be seriously reduced.

TELEPHONE LINE WORK IN THE UNITED STATES.

By E. S. Byng, Member.

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Summary.

The object of this paper is to place before members of the Institution observations made during a trip to the United States upon some of the practices adopted in line construction work. The treatment is mainly descriptive and, in general, no attempt is made to estimate the advantages or disadvantages of American telephone methods in comparison with those adopted in other countries. The scope of the paper is indicated in the Table of Contents given below.

Table of Contents.

(I). Introduction.
(II). Staff organization.
(III). Development studies.
(IV). Design and lay-out of plant.
(V). Engineering and constructional methods.
(1) Pole routes.
(2) Aerial cables.
(3) Conduit routes.
(4) Underground cables.
(5) House cabling.
(6) Block cabling and wiring.
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(VI). Transport.
(VII). Mechanical and labour-saving devices.
(VIII). Maintenance.
(IX). Conclusion.

SECTION I.

Introduction.

After the author's return from a recent visit to the United States of America, it was suggested to him that in view of the difference between the methods of telephone line construction adopted in the two countries, a paper describing the essential features of the present-day practice in the United States would prove of interest to British telephone engineers.

The methods of construction employed by the British Post Office are well known and are fully described in the several technical instructions issued by the Post Office Engineering Department. The methods adopted in America are, however, not so well known in this country, and an account of their distinctive features will, it is hoped, form the basis of a useful discussion.

In America, the home of the telephone, the possibilities of the invention were quickly appreciated and expert skill was bestowed upon its scientific development from its inception. These conditions may have had a great deal to do with the rapid progress of the telephone in the United States. That country now contains about 70 per cent of the telephones of the world, and the engineers concerned have therefore enjoyed a better opportunity of developing and improving their plant methods than has been afforded elsewhere. Their work has been carried on in comparatively new cities which were growing rapidly, and among people who regarded the telephone not as a luxury but as a necessity of business and social life. The field, moreover, was left open to commercial enterprise. Telephone development in America was thus stimulated to a degree to which no other country affords a parallel.

SECTION II.

Staff Organization.

In order that the evolution of telephone practice in America may be understood, the organization in force will be briefly indicated. The American Telephone and Telegraph Company (referred to hereafter as the "A.T. & T. Co.") and its associated and connecting companies, constituting what is commonly known as the Bell System, control approximately 12 600 000 telephone stations. In addition, there are about 900 000 stations owned by independent companies, not connected in any way with the Bell System, but competing directly with it in certain territories. The entire country is covered by these associated companies.

Each company has its local organization, the operating side being generally divided into 4 major divisions, i.e.

(1) Engineering.
(2) Plant.
(3) Traffic.
(4) Commercial.

The chief officer of each department is directly responsible to a vice-president or general manager of the company. Fig. 1 shows the organization of one of these companies.

The allocation of the work among these departments will be understood by the following outline of their respective responsibilities :—

(1) *Engineering Department.*

(*a*) The technical standards employed in the design, construction, and operation of the plant.
(*b*) Preparing the exchange and toll fundamental plan.
(*c*) Preparing the provisional estimate.
(*d*) Inventories and appraisals and other work on rate cases.
(*e*) Recommending sites for buildings, preparing general plans and estimates for buildings, and advising architects when necessary.
(*f*) Preparing specifications and estimates for central-office equipment in conjunction with the traffic engineer and the Western Electric Company.

(*g*) Study and application of the technical standards for construction materials and methods, equipment, transmission, and protection, and other general engineering standards recommended by the A.T. & T. Co., and for providing the Plant Department with the necessary instructions with respect thereto.

(*h*) Review and approval (or constructive criticism) of plans and estimates of cost for extensions and additions to the outside plant prepared by the Plant Department.

(2) *Plant Department.*

(*a*) Recommending all outside plant extensions and additions to meet contemplated growth; and making plans and estimates of costs for the construction and reconstruction work involved. Toll and trunk circuit requirements are set up by the Traffic Department, and those relating

(*c*) Traffic data for the fundamental plan.

(*d*) Handling of traffic.

(*e*) Training of operators.

(*f*) Observation and inspection of the service rendered.

(*g*) Arrangements for co-operating with the Traffic Departments of other companies of the Bell System and for giving proper assistance to, and co-operating with, connecting companies in traffic matters.

(4) *Commercial Department.*

(*a*) Determination of local rate areas and rates, and suburban toll rates.

(*b*) Commercial basis for the fundamental plan.

(*c*) Compilation, publication, and distribution of telephone directories.

(*d*) Publicity and advertising work.

(*e*) Commercial relations with connecting companies.

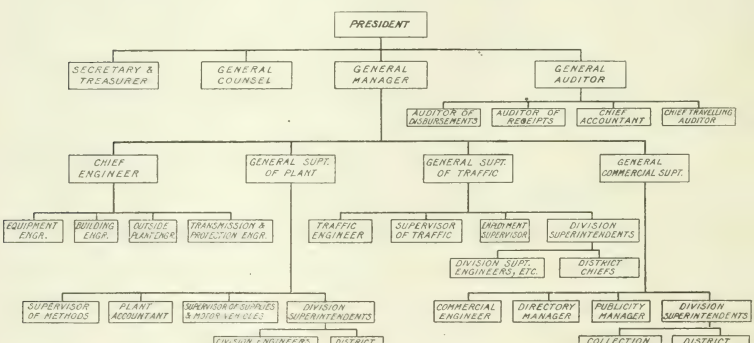

FIG. 1.—Bell Telephone System: typical staff organization of an operating company.

to station growth by the Commercial Department.

(*b*) Keeping the plant records.

(*c*) Obtaining all rights of way.

(*d*) Construction of the line and station plant, and in certain cases (the majority of which involve only minor additions), the installation of central-office plant.

(*e*) Maintenance of the telephone and real-estate plant in its entirety, including such items as general equipment, tools, and vehicles.

(*f*) Ordering and distributing material and supplies, making plant pay-rolls, and keeping account of the plant use of material and labour.

(3) *Traffic Department.*

(*a*) Recommending all additional central-office equipment and all additional trunk and toll circuits required by the growth of business.

(*b*) Study and application of standard traffic practices recommended by the A.T. & T. Co.

(*f*) Predicting growth in business.

(*g*) "Selling the service"—a term comprising canvassing, collecting, etc.

The responsibilities of the Plant, Traffic, and Commercial Departments are necessarily distributed over the territory of each company, and the staffs are correspondingly located. The Engineering Department, however, is a general head-quarters staff and is so placed in the organization that all projects for addition to the plant must receive the chief engineer's approval before being acted on by the Executive Committee. In the last analysis no small measure of direct responsibility rests with the chief engineer in the matter of producing a fair return.

The details of the organization which reports to the divisional superintendents depend very largely upon the size of the territory controlled. In some cases a greater amount of functional, rather than sectional organization, is advisable; in other cases, where the

centres are widely apart, sectional organization appears to have many advantages.

Each associated company furnishes the exchange telephone service for the cities, towns, and villages situated within the territory over which it operates; it also provides a local trunk service between one place and another within the same territory. Systems of long-distance trunks between towns in different territories are furnished by the Long Lines Department of the A.T. & T. Co. Although it forms a part of the main company, this department is managed practically as a separate company and has its own organization covering the whole of the country.

The A.T. & T. Co. constitutes the central controlling organization for the whole of the Bell System. The technical side of the head-quarters staff consists of two main departments, the Department of Development and Research, and the Department of Operation and Engineering, each under the charge of a vice-president of the company. These departments act in an advisory and consultative capacity for the associated companies, and it is due to this organization that a standardized telephone system has been established throughout the United States.

The officials of the associated companies are in close touch with the general departments, and thus keep themselves informed of the best practice in their particular branch of telephony. The associated companies do not undertake any broad technical development, research, or standardization work, this duty being performed by the central organization.

In addition to the Technical Department of the central organization, the engineering staff of another of the associated companies in the Bell System, the Western Electric Company, is called upon to develop new devices and to carry out all laboratory investigations and tests. The Western Electric Company is responsible for the manufacture of all telephone apparatus and cable for the Bell System; it also acts as purchasing agent for all auxiliary supplies conforming to specifications prepared by the A.T. & T. Co.

SECTION III.

Development Studies.

A forecast of the development for many years ahead is necessary in order to secure an efficient telephone system. This forecast forms the basis for a number of important phases of planning and engineering, such as the lay-out of exchange areas, current-rate treatments, fundamental plant and equipment plans, and provisional estimates and budgets.

The fundamental plan, and the collateral studies based on the fundamental plan data as developed, are expected to indicate :—

(*a*) The general ultimate conduit system ;
(*b*) The locations of existing and proposed central offices ;
(*c*) The economy of establishing new branch offices or of enlarging or replacing existing central offices, when the location of the office is involved ; and
(*d*) The most appropriate design of subscribers' and trunk cable plant.

The investigation required for these purposes is known as a " Commercial Survey," and is made by the Commercial Engineering Department on the following lines :—

(1) An analysis of all existing telephone subscribers is prepared from existing records. As American cities are usually laid out on a rectangular block plan, a separate record is made for each block, which forms a convenient unit for telephone distribution. Details of the class of service are also given.

(2) A survey of each block is made to ascertain whether the existing subscribers should be classed as :—(*a*) " Business," and, if so, the exact class of business is recorded ; or (*b*) " Residence," in which case particulars as to the number of families, type of house (whether private, flat, apartment, etc.), and rental value per month are obtained. At the same time, similar information is compiled of all non-subscribers in the block.

(3) Two sets of ordnance maps on a suitable scale are prepared, one to show the recognized " wards " into which the town is divided, and the other the areas where the conditions are considered to be uniform. The latter were originally known as " homogeneous " sections, but the term now generally used is " market " sections. It is usually found that there are certain neighbourhoods the character of which is more or less uniform ; for example, where people of one race form a colony in a town. Further, one district may be purely artisan, whereas another may contain nothing but high-class residential property ; and so on. The maps showing the " wards " and " markets " sections are superimposed to obtain what is known as " working " sections, which are in turn used as the basis for the study of development. A " working " section will contain a number of blocks, but it can, if necessary, be further sub-divided for the purpose of accuracy in final distribution.

(4) The information obtained under (2) is summarized for each " working " section, so that the total number of subscribers and non-subscribers can be obtained in any form subsequently required ; that is to say, for the town as a whole, in " wards," or in " market " sections.

(5) The various local characteristics are considered ; for example, census figures for population and number of families ; statistics regarding school enrolments ; birth rates ; death rates ; reasons for excessive growth or retardation ; the position of a town in relation to neighbouring towns ; transportation facilities ; industrial activities which may determine the growth of the town for the next 20 years ; the probable trend of building development ; the ratio of the number of telephones to the number of

families compared with the proportion in towns similarly situated; and, finally, the effect of possible increases or decreases in the telephone charges upon the use of the service by the various classes of families. Forecasts of telephonic growth are made in relation to "families" rather than to population, as they are considered to afford a more reliable standard.

(6) On the basis of a comprehensive study of all such local characteristics by the Commercial Engineering Department, a map is prepared showing the estimated development for each "working" section during the planning period decided upon for the town concerned. For a fast-growing territory a 15-year figure is taken; under normal conditions, however, the period is 20 years. Intermediate figures for 6-year and 12-year periods are also given, as these facilitate the preparation of the fundamental plan.

SECTION IV.

Design and Lay-out of Plant.

The fundamental plan is intended to show the general lay-out of telephone plant in a city over a definite period of 15 to 20 years, in accordance with the development study. Such a plan gives the situation of the exchanges and conduit routes, both existing and proposed. The new conduit routes are laid out so as to give the most direct path from the exchange to any block, following a definite plan of distribution. The disposition of the existing plant, being a controlling factor in many instances, is also taken into consideration. The fundamental plan does not attempt any refinement of detail; it is a rough conjecture of the probable telephone requirements. The proposed main routes are indicated, but the actual installation is not begun until it is required by growth, street improvements, or local regulations. In other words the fundamental plan serves as a general guide to the plant engineers, so that, when a plant extension has to be made, it may be of the proper size and correctly arranged.

Fundamental plans are usually reviewed every five years, so that, as far as possible, a comprehensive, consistent, and economical system of distribution is secured. In general, an underground conduit system is adopted in all main thoroughfares and business streets; in the outskirts of a city, and for distribution work, aerial cables are used extensively. The limiting lengths of the various sizes of copper wire, which are dependent upon transmission requirements, are determined for the exchange area as a whole.

The block-building system lends itself very conveniently to a symmetrical lay-out of plant. As already indicated, the plant engineer takes a block as a unit for telephone distribution. The dimensions of a block are generally 600 ft. long by 400 ft. wide. In the business sections, where a large number of circuits are required, a block is divided into several sections, each of which is served by direct "house" cables. Where the telephone density is not so great, block-wiring—either external or internal—is adopted. In "thin" areas it may be economical to arrange the distribution from short poles erected either in the alleys within the block or in the roadway between adjacent blocks. The methods of distribution are described in more detail in Section V.

Reference has been made to the use of aerial cables. Ever since the days of overloaded open-wire routes the advantages of the aerial cable as an economical means of providing telephone service under certain conditions have been realized. On the other hand, aerial cable was at one time considered to be a transition stage between open-wire and underground construction. Owing to ring cuts, crystallization of the lead sheath which occurs at poles, and other defects which were frequently the cause of breakdowns, it was deemed advisable in many cases to place important long-distance cables underground in order to ensure continuity of service. As a result of close investigation the defects mentioned were gradually eliminated in the case of subscribers' cables, and the success thus obtained caused the engineers to turn their attention to long-distance cables, with the result that it is now settled policy, where local conditions permit, to run all long-distance cables aerially. The advantages and disadvantages of aerial cable, as compared with underground cable, are further discussed in the latter portion of Section V (2).

The question of the actual type of plant to be adopted is always considered from the standpoint of economy; but, in addition, features of safety, the quality of service to be provided, and the desire to set up conditions satisfactory to the public, are important considerations which are taken into account. In cost studies both the first costs and the annual costs are included for a period over which unequal facilities exist, or up to a time when a definite procedure will be followed regardless of which plan may be adopted at the outset. In this manner the required facilities can be secured with a minimum expenditure throughout the life of the plant involved.

Subscribers' cables are referred to as either main or distribution. The term "main cable" is considered to mean the large sizes of cable radiating from an exchange, into which the distribution cables are jointed. The distribution cable is the branch cable which feeds the actual distribution points. The standard sizes of No. 22 B. & S. gauge cable (10 lb.) range from 25 to 900 pairs, plus 1 per cent for defects. If a greater number of pairs is required in a $2\frac{6}{8}$-inch diameter of lead sheath—known as "full-size" cable—No. 24 B. & S. gauge ($6\frac{1}{2}$ lb.) conductor is used. With these conditions a 1 200-pair cable can be obtained. The latter cables are used in fast-growing areas and in the main runs of larger cities where transmission requirements permit. Experiments are now being conducted in order to ascertain if it is possible to manufacture and use a No. 27 B. & S. gauge cable ($3\frac{1}{4}$ lb.) in large telephone cables planned for 1 500 pairs.

In all subscribers' cables a colour code is adopted. For main cables the distinctive coloured pairs are arranged in groups of 100, plus 1 per cent, so as to facilitate testing and numbering through. For a

1 200-pair cable the colour code for the paper insulation is as follows :—

Group	No. of Pairs	Colours of Wires
1	100	Red-White
	1	Red-Orange
2	101	Blue-White
3	101	Orange-White
4	101	Green-White
5	101	Red-Blue
6	101	Red-Green
7	101	Red-White
8	101	Blue-White
9	101	Orange-White
10	101	Green-White
11	101	Red-Blue
12	100	Red-Green
	1	Red-Orange

The paper wrapping is applied to the wires in a spiral and therefore no cotton binding is required to hold it in place. Two wires are twisted together to form a pair, and the pairs are stranded in layers. In "quadded" cable, the two pairs forming a "quad" are each served with a cotton binding, but there is no serving over the "quad."

Some years ago, in America, it was considered that lead alone did not possess the mechanical properties essential for a satisfactory cable sheath. The requirements were that the sheath should be capable of enduring a reasonable amount of abrasion, of bending without kinking, and also of resisting chemical action. It was found that an alloy of 97 per cent lead and 3 per cent tin had the requisite mechanical strength, even when the thickness of the sheath was reduced. Owing to the increasing price of tin, experiments were made with other alloys, resulting in the final adoption of an alloy of 99 per cent lead and 1 per cent antimony for cable sheaths of both overhead and underground telephone cables. Before the cable is sheathed a layer of red paper is placed over the complete core for the purpose of enabling workmen to separate scrapped sheath, so that antimony-alloy sheath and tin-alloy sheath may not become mixed. It also serves as an indication to jointers that the sheath contains antimony.

In planning the cable lay-out in the centre of a large city it is not usual to consider diminishing or tapering main cables. The objection to opening main cables for the purpose of transferring branch cables to afford relief, or for connecting new branches, has been removed by the provision of large stubs. The method of jointing stub cables is dealt with in Section V (4).

Wherever it is anticipated that branches will be jointed-in at any later date, arrangements are made to bring out a stub cable containing a number of pairs equal to the sum of the ultimate number of pairs in the branch cables, plus a percentage of pairs for flexibility and changes in the distribution. The size of the stub cables, however, does not exceed that of the cable to which they are connected, and preferably they are arranged in even hundreds, to comply with the colour code. The distribution at a given point is confined to one cable, and the cable is so arranged that all its branches are in adjacent manholes. In practice the same numbers are brought out at two or more points, and when relief cable is provided care is taken to avoid any change in the numbering of the cables at the main frame. The first cable feeds a permanent area between the exchange and the suggested relief point, and also a temporary area beyond this point. When the further cable is installed, the original cable is cut at the point of relief without the necessity of transferring any of the stubs or branches. This arrangement is shown diagrammatically in Fig. 2.

In a rapidly-growing territory the question of relief is often considered when the cable is serving 60 to 65

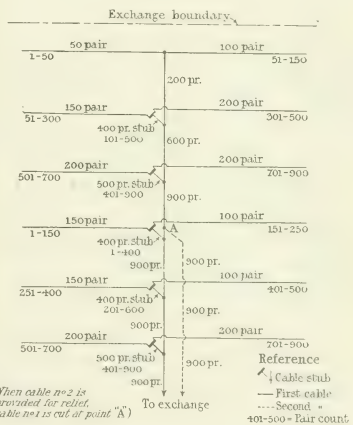

FIG. 2.—Cable lay-out.

per cent of its total pair capacity. It rarely happens that the construction staff is obliged to open joints in the main cables, this process being avoided on account of the possibility of introducing defective pairs and the danger of lowering the insulation resistance.

The plant engineer makes himself familiar with all the details of the plant within his jurisdiction, and by means of card records is kept informed as to the "fill" of the cables, so that new development studies may be made which will enable him to plan any construction work simultaneously with the relief of congestion. Unless he has this detailed knowledge of the plant and also of the character of the growth, it is impossible for him to plan an efficient telephone system. To this end he has, in addition to the fundamental plans, a series of maps giving detailed information of all existing plant. These are known as "plant study maps" and

are intended primarily as a guide to the plant engineer in efficiently arranging for relief and the extension of plant. There is very close co-operation between plant engineers and the commercial department, ensuring that the more urgent work receives prior attention, and that canvassing does not take place before the necessary plant is available.

SECTION V.

Engineering and Constructional Methods.

(1) Pole Routes.

(*a*) *Poles.*—The poles, which are generally of chestnut, white, red, or Western cedar, are classed "A" to "G," according to the circumference at the top and the circumference 6 ft. from the butt. Reinforced concrete and iron poles are not used, as at present timber can be readily obtained direct from the forests. Where the site of erection is remote from a forest or pole yard, creosoting is regarded as a measure of economy. Locally-hewn timber is frequently butt-treated with creosote oil. A gain of 5 to 15 years may be expected, depending upon the treatment applied. Brush treatment gives a gain of approximately 5 years, while open-tank treatment, providing for the penetration of the preservative to approximately $\frac{1}{4}$ inch, will give an increase in life of 15 years or more.

The provision of a reinforced-concrete belt round the pole at the ground line is considered to be beneficial in certain cases, but, unless it is properly applied, moisture will accumulate between the reinforcement and the pole and, instead of prolonging the life of the pole, will cause more rapid deterioration.

Main telephone routes generally follow the public roadways, but short cuts across country are frequently made where rights-of-way can be obtained. When negotiating for private easements a lump sum payment per pole, rather than an annual rental per pole, is offered in complete discharge of the required facility. The amount paid for the facility looks more attractive to the owner, and the clerical work involved in making periodical payments is abolished. Wherever possible the form signed by the owner also gives the telephone company the right to trim any trees along the route so as to ensure a clearance from the wires of at least 18 inches. When taking a main route through a forest an attempt is made to minimize the number of faults arising from contact with branches and falling trees by securing a 40-ft. cut through the forest, i.e. a 20-ft. clearance on either side of the route. The size of pole ranges from 30 ft. to 35 ft. for main routes, and is about 25 ft. for rural lines. Where a pole route is to be used for distribution within blocks—a case referred to as a "rear property pole line"—the length of pole is frequently only 20 ft.

Poles are spaced at from 100 to 150 ft. apart, according to the number and weight of conductors to be carried. Except in special cases long spans are not permitted, as the cost of such special construction is an item of prime importance, in addition to the serious expense of maintenance during bad weather conditions. On toll line routes the stouter poles, classes A and B, are used and are spaced 100 to 110 ft. apart. The tendency to-day is to use the former for open-wire toll lines, and the latter for cable lines. Pole roofs are not used, and it is not considered necessary to provide earth wires as protection against lightning.

Before a pole is erected, locations are decided well in advance of the construction gang by means of ranging rods. Circular pole-holes are excavated by means of special spoon-shaped shovels and long bars. The hole is sufficiently large to admit of the use of the tamping iron all round the pole, but less ground is disturbed than when a stepped rectangular hole is excavated. Pike poles and a tool called the "dead man" are used for pole erection in preference to ladders if a derrick operated from the rear of an automobile truck is not available. In favourable circumstances a construction gang of 12 men can excavate for and erect thirty 25-ft. poles (each carrying one arm) in an 8-hour day, without

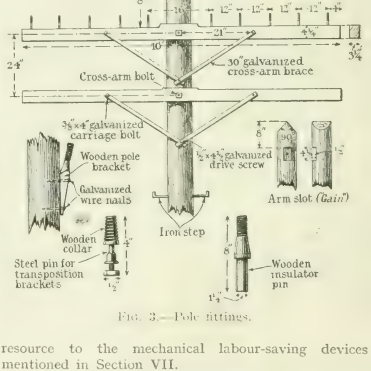

Fig. 3.—Pole fittings.

resource to the mechanical labour-saving devices mentioned in Section VII.

(*b*) *Arms.*—For exchange and toll line construction the standard arm has a normal capacity of 10 wires and is known as a 10-pin cross-arm. Two iron straps, known as "cross-arm braces," are used for preventing tilting of the arms; they do not interfere with the erection of the wires. Fig. 3 shows the fittings for a pole carrying two 10-wire arms. Double sets of arms are used at corner poles with a pull of 35 ft. or more, and also at certain special points, such as railway crossings, long spans, and test-poles.

(*c*) *Pole brackets.*—Where a maximum of only two or three circuits is required for some years ahead, wood-pole brackets are used, as they save the cost of providing a 10-wire arm.

(*d*) *Pole steps.*—It is not usual to provide pole steps on through routes. Linesmen are provided with climbing irons. At terminal poles and distribution points arrangements are made for permanent stepping.

(*e*) *Staying.*—There are several types of stay rod

(guy rod) which can be installed by means of earth borers, some of which are shown in Fig. 4. In general these rods give very good service. They can be used for anchoring any size of stay wire, with the possible exception of 16 000-lb. wire. On heavy lines, where the patent rod is not considered to be satisfactory and 16 000-lb. strand wire will be required, logs or planks are used to form the anchor. In all types of stay rod the top forms a closed ring, approximately 6 inches above the ground. The guy wire or strand, which is used for staying purposes and also for the suspension

Small stones
Strike here to expand
(a) Cone anchor
(b) Expanding ("Everstick") anchor
Plate holder for lowering plate into hole
"Never creep" anchor rod
Plate
Wrench clamped to rod to screw anchor into ground – No excavation is necessary
(c) "Never creep" anchor
(d) Screw anchor

FIG. 4.—Types of patent stay rods (anchors).

of aerial cables, is composed of seven strands of galvanized mild steel wire formed into a cable of the following sizes :—

Size	Diameter of Strand	Gauge of Wire	Minimum Breaking Weight	Weight per 1 000 ft.
lb.	in.		lb.	lb.
2 200	3/16	16 B.W.G.	2 300	75
6 000	5/16	12 B.W.G.	6 000	210
10 000	3/8	11 B.W.G.	11 500	295
16 000	7/16	9 N.B.S.	18 000	415

A turnbuckle, swivel, or other device for adjusting the tension on the wire after installation is not considered to be necessary. The wire is terminated by one or more 3-bolt guy clamps at each end. These clamps are fixed very quickly with the aid of a small pair of blocks which pull up the wire to the required tension. Poles situated at angles are given a slight set and, in practice, it is seldom found necessary to release any clamp subsequently for the purpose of tightening the wire. Strain plates are placed round the pole at the point of making off in the case of 10 000-lb. and 16 000-lb. strand. Where a stay wire is attached to a pole carrying electric light wires, or is immediately adjacent thereto, a strain insulator is inserted in the guy wire as a protection against accidents.

(*f*) *Insulator bolts.*—Insulator bolts (pins) are constructed of locust wood, a local and durable timber. The pin is simply driven into the 1¼-inch hole provided in the arm, and held in place by a nail. On transposition brackets steel pins are used, but they are fitted with wood collars to enable the standard type of insulator to be used.

(*g*) *Insulators.*—Various materials have been tested in the search for an insulator suited to American conditions, and glass, in conjunction with wooden pins, has been found to give the best results. At one time single-shed insulators were used exclusively, but, as the insulation resistance was found to be insufficient for high-grade toll line work, the double-petticoated insulator was introduced. The latter is now used when running or transferring all loaded circuits, and also in non-loaded circuits over 100 miles in length. Its use may also be justified on shorter circuits when insulation conditions are very severe. On subscribers' circuits the single-shed insulator is quite satisfactory. Double-shed porcelain insulators have been used, and there are still many in use; but these are considered obsolete, and glass is now the standard for all purposes.

(*h*) *Class of wire.*—For toll lines a No. 8 B.W.G. (435 lb.) or No. 12 N.B.S. (173 lb.) hard-drawn copper wire is used almost invariably, but for exchange circuits either No. 12 B.W.G. (165 lb.) and No. 14 B.W.G. (96 lb.) galvanized iron wire, or No. 12 and No. 14 N.B.S. (102 lb.) copper wire is employed. Galvanized iron wire is adopted in slow-growing outer portions of large exchange areas, and in all portions of the smaller exchange areas subject to the following conditions :—

(i) That the anticipated development is less than 10 lines in a 15-year period.
(ii) That the iron wire will have a life of 8 years or more.
(iii) That transmission requirements are fulfilled.

Where lines are exposed to moist air or the smoke from soft coal, experience has shown that iron wire will not last 8 years. Consequently copper wire has to be used for the majority of open-wire lines in the Eastern States.

Bronze and copper-clad steel are not used to any extent as overhead conductors, except as covered "drop" wires for distribution purposes. These covered wires are also adopted on subscribers' routes where the development studies indicate that the maximum number of circuits in a 5-year period will be six, and where the route does not exceed 1 000 ft. in length. When only three or four of such leads are required arms are not provided, small iron brackets carrying porcelain knobs being fitted on the pole. The number of open wires for local routes is limited where possible to 30, i.e. the full capacity of three 10-wire arms. When the number of circuits exceeds the figures mentioned it is probable that cable can be justified at the outset. The joint use of poles for telephone and electric supply wires is

greatly encouraged. The advantages are mutual, particularly on small routes used for distribution purposes.

(*i*) *Jointing and binding-in.*—For jointing hard-drawn copper wires a copper sleeve (McIntyre) is almost universally used in preference to a twisted and soldered joint. For galvanized iron wire, steel tubes are used, but it is also standard practice to twist and solder. At straight-through insulators a piece of soft wire of the same material as the through wire is used for tying-in and binding the line wire.

(*j*) *Termination of open wires on poles.*—At distribution or opening-out points circuits are terminated on straight insulator pins. On exchange circuits No. 18 B. & S. (26 lb.) insulated bridle wire is used for terminations and cross-connections. On high-grade toll circuits a No. 14 B. & S. (65 lb.) insulated wire is used. In both cases the covered wire is supported underneath the arms in small bridle rings. Prevention of leakage on high-grade toll circuits is effected, wherever bridle wire is used for terminating purposes, by the interposition of an additional insulator (made of a material known

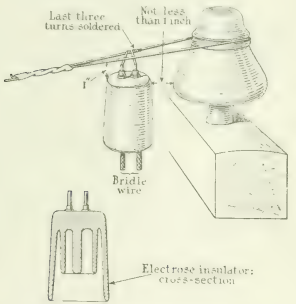

FIG. 5.—Termination of high-grade toll wire, using electrose insulator.

as "electrose") in conjunction with the glass insulators. The bridle wires are threaded through the metal tube inserts and soldered at the top, thus sealing the holes, as shown in Fig. 5.

(*k*) *Superimposing.*—On a toll or long-distance line practically every pair of physical circuits is used to obtain a third or phantom circuit by the installation of repeating coils at the terminating ends. The phantom circuit has been proved to be a better circuit than the side circuit, and is therefore a very profitable proposition. A further utilization of the plant is obtained by each of the four wires forming a group being separately composited for telegraph operation. A still further development is that by the application of "carrier" currents each pair of wires can be utilized for several simultaneous telephone or telegraph circuits. This advancement in the art greatly increases the value of open-line plant, but necessitates a high degree of efficiency in its construction and maintenance.

(*l*) *Transposition.*—All open-wire circuits in America are run straight. Only one arm is therefore required on a pole route which carries five pairs of wires. A system of transposition is adopted for long-distance lines. Two methods of transposition have been worked out in a very thorough manner, one for "exposed" and the other for "unexposed" lines.

Apart from this method of avoiding electrical interference, measures are frequently suggested to the electric supply companies by the telephone companies for the elimination of the higher harmonics which from time to time cause serious electrical interference with telephonic speech. Each cause of trouble is studied as it arises, and the endeavour always is to reach an arrangement which is mutually satisfactory and compatible with economy.

The standard numbering of wires on a pole route of two 10-wire arms is given in Fig. 6 (*a*). Wires 5,

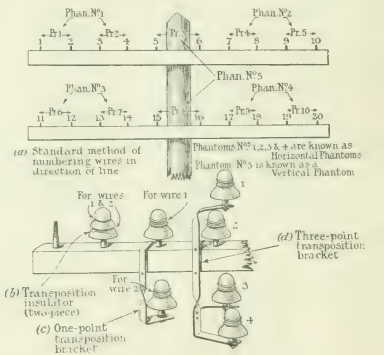

FIG. 6.—Numbering of wires, and transposition brackets.

6, 15 and 16 comprise what is known as the "vertical phantom circuit."

For a single-circuit transposition on an ordinary toll or long subscribers' circuit a special type of transposition insulator is used. It consists of a 2-piece insulator, each piece having a groove. A special 9-inch transposition pin carrying two sets of threads is necessary to provide sufficient clearance above the cross-arm.

On a high-grade toll circuit a bracket is fitted to carry the second wire. A special method of transposition is employed on lines which are included in a phantom group. Not only must the wires in the original metallic connection or side circuits be transposed, but the phantom circuit must be balanced by transposition against its own side circuits as well as against other phantom circuits on the same pole. A 3-point transposition bracket has been devised for this purpose. The three methods are illustrated in Figs. 6 (*b*), 6 (*c*), and 6 (*d*). One method in which transpositions are

made on side circuits and phantom circuits is shown in Fig. 7.

There are eight combinations possible for transposing the four wires forming a phantom group. The actual type of transposition and location in relation to other circuits is decided for each route after survey. When the wires are erected by means of a running board the pairs can be transposed separately, or the position of the pairs changed for a phantom transposition simply by releasing the spring latch on the eye to which each pair is attached.

(*m*) *Loading of open wires.*—Until the advent of the repeater, the practice of loading long-distance lines was adopted in America for circuits using No. 8 B.W.G.

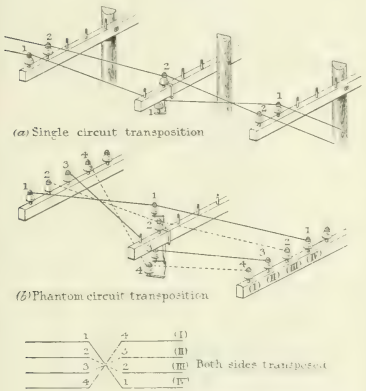

FIG. 7.—Methods of transposition.

and No. 12 N.B.S. copper. In the case of existing No. 8 B.W.G. circuits, where repeaters have since been installed, the loading coils have been removed, that is to say, the wires have been "unloaded." In the smaller size of wire, however, loading coils are required and are still being fitted in conjunction with repeaters. A complete unit of loading, which consists of three coils, two for the side circuits and one for the phantom, mounted in a pot suitable for fastening to the pole, is used in conjunction with a lightning arrester to protect the coils.

(2) AERIAL CABLES.

The same general principles are followed in the installation of both exchange aerial cables and toll line aerial cables.

(*a*) *Type and class of cable.*—Cables containing small-gauge conductors No. 22 B. & S. (10 lb.) are supplied in two types, one for aerial use, and the other for underground use. The underground type is not used aerially on account of its low dielectric strength, and the use of the aerial type for underground purposes is not economical. The sheath, however, is the same in both cases. Cables containing conductors of 20 lb. and heavier are identical, whether for aerial or underground installation. The largest size of these cables can be installed aerially if required.

(*b*) *Methods of suspension.*—Before a suspension strand is run out all necessary guying is completed at terminal points, corners, road and railway crossings, and at extremities of long spans. Where a class A pole route is carrying one or two cables only, it is not generally considered necessary to fix storm stays. The suspension strand is the same as that used for guying, particulars of which were given in the table on

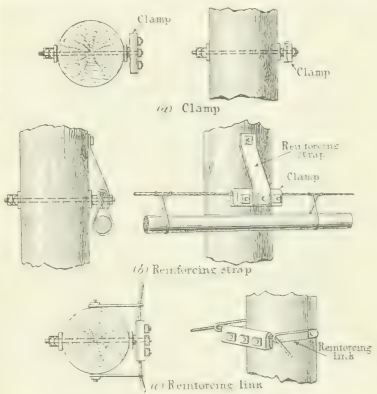

FIG. 8.—Suspension-strand fittings.

page 91. The sizes of strand required for various cables are given in the table below:—

Size of Strand	Maximum Size of Cable, No. 22 B. & S.	Maximum Diameter of Cable	Maximum Weight of Cable, per foot
lb.		in.	lb.
6 000	100-pair	$1\frac{1}{16}$	2·25
10 000	300-pair	$1\frac{3}{4}$	4·95
16 000	Over 300-pair	Over $1\frac{3}{4}$	Over 4·95

The strand is attached to the pole by means of a clamp, as shown in Fig. 8 (*a*). Where the cable supported exceeds 2 inches in diameter a reinforcing strap is used [see Fig. 8 (*b*)]. At corner poles a reinforcing link is fitted as indicated in Fig. 8 (*c*).

Where new poles are provided, the suspension strand

is generally fixed about 14 inches from the top of the pole. If ultimately the route is to carry two cables, the strand for the first is erected on the same side of each pole throughout, and the second may then be run without crossing the first. Suspension strand is requisitioned in reels up to one mile in length. On a long-distance toll cable several miles of suspension strand can be erected, without actual termination, by making straight joints in the strand as shown in Fig. 9 (*a*). Where the cable is terminated the strand is "made-off" on the pole, as shown in Fig. 9 (*b*). What is known as a "false dead end," constructed as shown in Fig. 9 (*c*), is formed on the suspension strand at

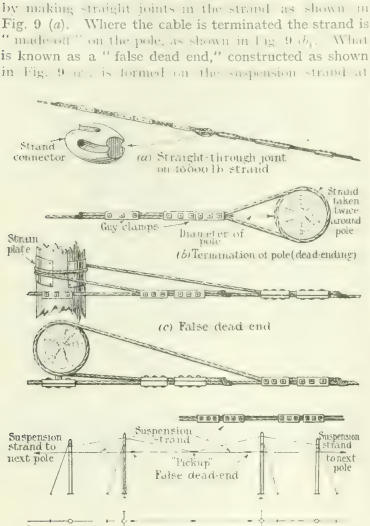

FIG. 9.—Suspension-strand jointing and terminations.

special points, such as steep gradients, crossings, pick-ups, etc. It has the effect of terminating the strand. A pick-up, in the case of a long span of cable, is shown in Fig. 9 (*d*).

The universal method of securing the correct tension of the suspension strand during construction is rather ingenious. The sag of each size of cable at various temperatures after installation, but without ice or wind load, is first ascertained, and from this the permissible initial tension in the strand is determined. The construction gangs measure the tension of the strand during erection by a method of vertical oscillations. A light rope is thrown over the strand at the centre of the span, where there is no joint, and by giving the rope an up-and-down movement (a process known as "pumping") the strand also is caused to move in rhythm. By comparing the counted number of complete oscillations over a period of 15 seconds with the figures tabulated for each size of strand for varying lengths of span at different temperatures, the men can adjust the tension until the correct number of oscillations has been obtained. The author was present on one occasion when comparative tests were made by means of a dynamometer, and it was evident that the oscillations method gave a much quicker and more satisfactory result. In shorter spans a 5-lb. weight is hung from the end of the hand-line, which is slung over the suspension strand, in order to damp down the number of oscillations. Provision is made for this in the schedule supplied to the men.

In the case of exchange cables it is frequently necessary to branch off a cable in one or both directions laterally. This can be done at mid-span, where perhaps it is not possible to erect a pole, by the formation of a cross-over in the suspension wire by bolting two cable suspension clamps at right angles. The **Y** or forked joint is made at least 24 inches away from the junction, and is secured to the strand by marline ties.

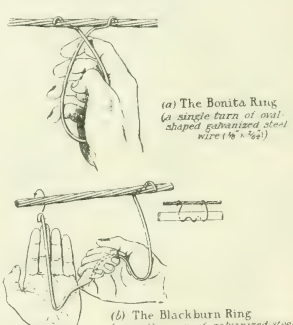
(a) The Bonita Ring
(a single turn of oval-shaped galvanized steel wire (⅛ × 5/32))
(b) The Blackburn Ring
(a cradle ring of galvanized steel wire (No 6 B.W.G.))

FIG. 10.—Method of fixing metal cable rings.

(*c*) *Cable rings.*—Marline, leather, zinc, etc., for the purpose of suspending cables from the strand, have been superseded by a round-section steel ring. The two types now largely used by the telephone companies are the "Bonita" and the "Blackburn." Figs. 10 (*a*) and 10 (*b*) show the method by which these are fitted. In both types of ring the ends are shaped for hooking to the strand. No tool is required for attaching or removing them. The rings are placed 16 inches apart on a 16 000-lb. suspension strand, and 20 inches apart on a 10 000- or 6 000-lb. suspension strand. At the pole the rings in all cases are placed 6 inches from the cross-arm bolt on either side. In the larger sizes of cable an additional ring is placed on each side, midway between the first and second rings, i.e. 14 inches on either side of the pole.

Prior to the erection of the cable, the rings are placed in position by a wireman who moves along the sus-

pension strand in a " bosun " chair. A tarred hand-line or galvanized iron wire is passed through the rings as they are fitted, for the purpose of pulling the steel hauling rope.

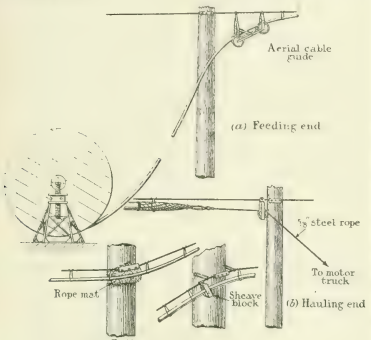

FIG. 11.—Erection of aerial cable.

(*d*) *Erection of aerial cable.*—The metal rings grip the suspension strand so tightly that they form practically an aerial conduit and do not alter their position during the installation of the cable. The cable drum is mounted on jacks about 30 ft. away from the foot

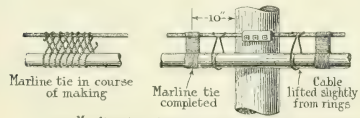
10"
Marline tie in course of making
Marline tie completed
Cable lifted slightly from rings
(a) Marline tie at pole (for prevention of ring cuts)
Bushed with cable sheathing
Grade clamp
(b) Grade clamp (for prevention of "creeping")

FIG. 12.—Marline tie and grade clamp for aerial cable.

of the pole, from which point the cable rises without intermediate support to the suspension strand. One end of the cable is dressed down by having two circular rings beaten in the sheath, and a wire grip is afterwards placed thereon. The $\frac{5}{8}$-inch steel hauling rope connected to the motor truck is pulled through the rings by means of the line inserted for that purpose. Usually an underhand feed is arranged, as shown in Fig. 11. A cable-running device, formed by a combination of two sheave blocks, is placed on the strand, 2 ft. from the pole at the feeding end. At corner poles where the strand pulls away from the pole a sheave block is used, but in the case where the strand pulls in to the pole, a rope mat is fixed to prevent abrasion of the lead sheath. On a straight run, a full-size cable of standard length (about 500 ft.) can be installed without any intermediate blocks or other gear if the cable is well lubricated before being started along the rings. For this purpose a thick motor oil is poured on the cable and then distributed by a piece of burlap, or oil is applied by means of a syringe.

(*e*) *Ties and grade clamps.*—For the purpose of preventing ring cuts on toll or large cables (from which

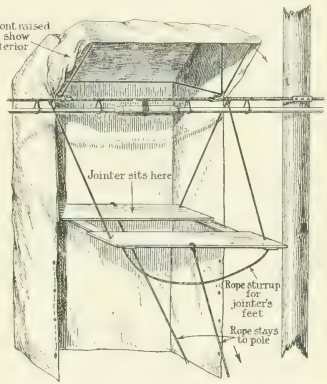

FIG. 13.—Platform and shelter for jointers on aerial cable.

there is little or no local distribution) a marline tie, as shown in Fig. 12 (*a*) is used on either side of the pole as a support. To some extent this is a temporary expedient, as experiments with special types of rings for installation at the poles seem to have more satisfactorily solved the problem. On gradients the cable is clamped to the strand by means of a marline tie or a metal grade clamp. The latter type of clamp is shown in Fig. 12 (*b*). A tie or clamp is fixed at the highest pole on the grade, after which its frequency (i.e. on every pole, or every second, third, or fourth pole) depends upon the steepness of the gradient. As the cable is rigidly fastened to its suspension strand, the tie or clamp prevents it moving along the rings after erection.

(*f*) *Cable jointing.*—Particulars of jointing operations will not be mentioned here, as details are given under Section V (4). The only exceptional feature in aerial cable work is the type of platform and jointers' shelter which has been devised (see Fig. 13). The platform

consists of two halves with a space between so that the jointer can rest his legs on a rope slung from the platform. The "helper" can also sit comfortably on the platform facing his jointer, if required. During stormy weather a collapsible tent is used, having sides which extend downwards sufficiently to keep the jointer perfectly dry. Where practicable, the position of the joint is arranged to be near a pole, so that a ladder will not be necessary for stepping on to the platform. The platform can be stayed to the pole to prevent undue rocking.

(*g*) *Bonding.*—On all aerial cables the practice of bonding the cable sheath to the suspension strand is adopted at every 10th span. A piece of lead strip or tinned copper ribbon is soldered to the cable and inserted between the two halves of a guy clamp, which is secured to the strand.

(*h*) *Terminations.*—In the case of an underground "dip" (i.e. where it is necessary to take an aerial

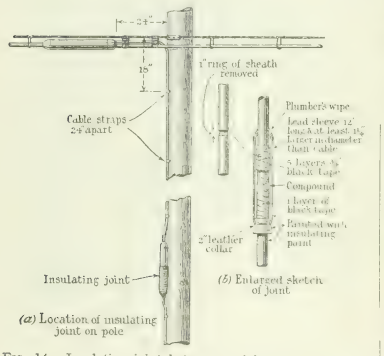
24"
18"
1" ring of sheath removed
Cable straps 24" apart
Plumber's wipe
Lead sleeve 12" long & at least ⅛" later in thickness than cable
5 layers ½" Black Tape
Compound
1 layer of black tape
Painted with insulating paint
2" leather collar
Insulating joint
(b) Enlarged sketch of joint
(a) Location of insulating joint on pole

FIG. 14.—Insulating joint between aerial and underground cable.

cable through an underground duct for a special crossing) it is unnecessary to terminate the cable at the two ends. Where, however, aerial cable is to be connected with underground cable, a terminal box fitted with sealing chambers, fanning strips and fuses, is used. These boxes are manufactured in standard sizes and the dry core paper cable is connected to the terminal posts in sealing chambers.

To break the electrical continuity of the cable sheath and thus prevent the flow of current along the sheath in the underground section where there is no cable terminal fitted, what is known as an "insulating" joint is made at some convenient point on the pole before the aerial cable is connected with the underground cable. An external type of insulating joint is shown in Fig. 14. A 1-inch ring of sheath is cut away, and five layers of tape are placed over this point, extending 1 inch over the sheath on either side; one layer of tape is also continued over the sheath on one side for a distance of about 12 inches. A lead sleeve is beaten down at one end over a few layers of rubber tape and a 2-inch leather collar; the sleeve is filled with compound, and the other end closed by a plumber's wipe.

Where an exchange cable is terminated externally for distribution purposes the terminal almost invariably used is known as the "No. 14 type." Details and also a sketch of this type of terminal were given by Mr. F. G. C. Baldwin in his paper "Some Considerations in the Manipulation of Dry-Core Telephone Cables" before this Institution.* It consists essentially of two elements, a galvanized cast-iron box and a porcelain block for mounting lock-nut terminals; 6-ft. or 9-ft. lengths of dry-core cable—fitted at either end as desired—are fanned out on the back of the terminal posts, the back being filled in solid with compound. The terminals are made in standard sizes, 11, 16, and 26 pairs. In order to connect them to the distribution cable it is

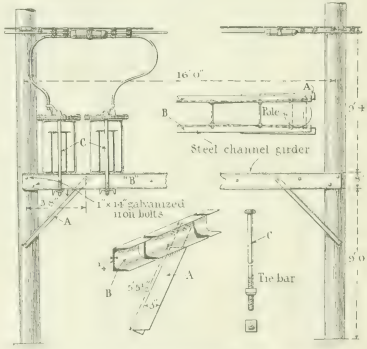

FIG. 15.—H-pole fixture for carrying loading coil cases.

necessary only to make a straight joint on to the end of the stub cable with which they are supplied.

An alternative cable terminal which is used to a limited extent in some parts of the United States is known as the "No. 8." This type is enclosed by a circular tin top, but, although it represents a satisfactory cable terminal in many respects, the No. 14 type is usually preferred.

(*i*) *Loading coils.*—For aerial cable loading the pot may be mounted on a pole, or placed in a manhole at the foot of the pole, or buried in the ground close to the pole. In the second and third cases an insulating joint is required. Wherever possible the first method is adopted, as much shorter stub cables are then required. A single spindle pot is attached to the pole by means of brackets; for multi-spindle types a small platform is erected on the pole. A full-size toll cable, to load which completely will probably require five or six pots,

* *Journal I.E.E.*, 1909, vol. 43, p. 643.

necessitates the erection of a special H structure. This consists of two poles erected about 16 ft. apart in line with the route. A steel girder (channel) is erected between the poles, the whole structure being suitably braced and supported for carrying the pots, as shown in Fig. 15. The complete structure provides an inexpensive and thoroughly stable means of accommodating the loading equipment for aerial cables.

(*f*) *Advantages claimed for aerial cable construction.*—The advantages of an aerial cable system for distribution purposes, due to its flexibility, are mentioned in Section IV. It is only during late years that American engineers have satisfied themselves that the practice of erecting toll cables aerially is economical where the ultimate number of full-size cables will not exceed, say, two. Each case is, of course, considered on its merits. In sections through towns an underground "dip" is invariably made, use being made of a spare duct included in the local telephone system. The advantages claimed for aerial toll cable are briefly as follows:—

(1) The initial investment for aerial cable in place is less than for similar cable placed underground, where both pole route and underground route have to be specially constructed. There is also a saving on the annual cost of aerial cable.
(2) Where the ultimate traffic is uncertain, there is less risk in the smaller investment. This applies also to the factor of obsolescence, which cannot be overlooked.
(3) The work of installation can be completed much more rapidly, and consequently there is an earlier return on the investment and an earlier service for the public.
(4) Aerial cable may be erected over rocky or mountainous country where underground construction would be impracticable.
(5) Reduction in cost and lower transmission losses may be secured by the more direct route which may frequently be followed aerially.
(6) River and canal crossings can be negotiated more easily by aerial than by submarine cable, provided the crossings are relatively short.
(7) Although there is a greater possibility of faults with aerial cable, repairs can be effected more readily. The cable is accessible at all points, without the necessity for withdrawing a section; service is therefore quickly restored. Further, underground cable is more liable to total breakdown from the flooding of ducts or manholes, due to defects in plumbing and other causes, than is aerial cable.
(8) Aerial cable is always open to inspection, and breakdowns due to street operations are avoided. Also, when roadways are being re-made, raised, or lowered, an aerial cable route may easily be diverted.
(9) There is practically no risk of electrolysis.
(10) During winter, underground cable is liable to be crushed within the ducts by the freezing of water. Aerial cable is exposed to no such danger.

The chief drawbacks to the use of aerial cable are:—

(1) The line may be objected to on æsthetic grounds. If, however, the construction work is carried out in a proper manner, a pole route carrying cable only is perhaps less objectionable than a heavy route of open wires.
(2) Ring cuts and also crystallization of the lead sheath (due to expansion and contraction of the cables) may occur. These serious drawbacks have now been overcome to a large extent.
(3) Injuries caused by gun-shot, malicious damage, linesmen's spurs, beetles and squirrels, and so on, have been mentioned as material risks, but in practice there have been very few breakdowns due to any of these causes.
(4) On account of the prevalence of wood buildings there is a possibility of damage to aerial cable by fire. This danger is minimized by skirting the villages and by underground "dips" through towns.
(5) Damage caused by blizzards to pole routes carying open wires engendered expectations of similar experiences with aerial cable, but during the past few years it has been demonstrated that where only cables are carried the route is practically immune from storm damage. In fact, the calculated strength of a new route of class A chestnut poles carrying two full-size cables is such that with $1\frac{1}{2}$ inches of ice on the suspension strands and cables, and a 70 m.p.h. wind velocity, there is a factor of safety of 4·7. It is calculated that after 19 years' life, with a loss of $\frac{1}{2}$ inch per year in the circumference of the pole, there is still a factor of safety of 2·0 under similar conditions.

In general it is claimed that the stability of an aerial cable route is assured by the precautions taken during installation. The chief points to be observed in planning such a route are: Short spans, extra stout short poles, removal of trees immediately adjacent to route, suspension strand at correct tension, the right class of ring at short, equal distances apart, marline ties to prevent crystallization and ring cuts, and grade clamps to avoid creeping. By the adoption of these measures many of the past weaknesses of aerial cable have been eliminated.

(3) Conduit Routes.

(*a*) *Types of conduit.*

(i) *Vitrified clay.*—The type of conduit very largely used by the telephone companies is made of a particular clay which has been highly vitrified. Single-way ducts are circular in bore, and multiple-way ducts are square with the corners slightly rounded off. The multiple duct is made in various sizes up to 9 ways, as shown in Fig. 16. Conduits with less than 4 ways are seldom installed, aerial cable being adopted, if conditions permit, where only one or two cables are involved. Various combinations of the standard sizes are made to obtain a larger number of ways, when required. All joints are staggered, both horizontally and vertically.

It is necessary to butt the ends together, two steel dowel pins being used at each joint to maintain alignment. Joints are wrapped with single thicknesses of a 9-inch strip of wet muslin plastered with ½ inch of cement mortar.

Multiple-way conduits are laid on a 4-inch concrete foundation, and in towns a top cover of concrete is frequently given as a mechanical protection. In city work, and where the sub-soil is marshy, concrete is sometimes used at the sides of the conduit, so that, together with the foundation and top protection, a complete envelope of concrete is formed round the duct line. It is recognized that such a liberal use of concrete adds considerably to the installation cost, but engineers consider it is a justifiable insurance against external

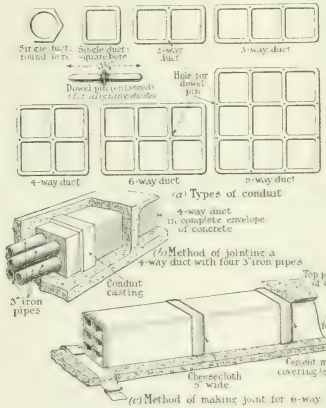

FIG. 16.—Types of conduit and methods of jointing.

injury. Experiments are at present being made to ascertain whether self-aligning ducts, fitted with spigot and socket joints, as used in this country and laid without concrete, are likely to be damaged when laid at normal depths.

At the time the conduit is laid a No. 12 B.W.G. (165 lb.) galvanized iron wire is drawn into one of the ducts to be used, for pulling in the steel hauling rope. The remainder of the ducts are rodded and wired as required.

(ii) *Creosoted wood.*—A single duct of creosoted yellow pine (known as "pump log") 4½ inches square on the outside and with a circular hole 3 inches in diameter, is also largely used. Lengths of creosoted wood duct vary from 3 ft. to 10 ft., including the tenon at one end and the mortise at the other, provided for jointing purposes. The two ends fit into one another, no nails, screws, or compound being necessary. Creosoted wood is used for both small and large runs where the cost of the wood is relatively low. Generally speaking, if more than 4 or 6 ways are required, vitrified clay is found to be the more satisfactory. It is common practice to provide an additional duct as a crown to a main conduit line, for the accommodation of future lateral connections. Creosoted wood duct is very suitable for this purpose, as it can be cut into at any point without interference with the main route.

(iii) *Iron or steel.*—Metal conduits are employed only for the lateral or "riser" at distribution points or where their use is unavoidable in negotiating obstructions. An iron connecting piece is used to link up steel pipes with vitrified clay conduits where a manhole is not required.

(iv) *Other classes of conduit.*—Fibre tubing has been used to a limited extent, but it is considered that as an alternative duct for telephone work fibre is not so satisfactory as the standard types previously mentioned. Concrete ducts were installed several years ago by some of the telephone companies but were not successful, on account both of the increased friction during the

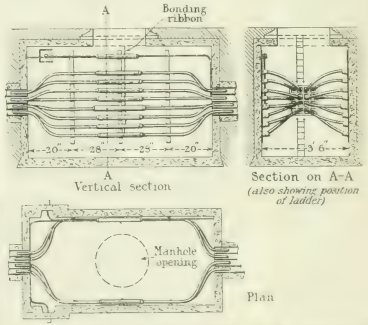

FIG. 17. Concrete manhole, showing fittings and position of cables.

installation of the cable and of the deleterious alkaline effect on the lead sheath.

b) Manholes.—Manholes were formerly constructed in brick but are now more frequently of concrete. The roof portion is reinforced with 6 000-lb. steel strand. Construction of concrete manholes is facilitated by the use of portable templates, made in such standard sizes that they may be braced together to serve for any size of manhole required. The manhole frame and cover are so arranged that entry is made in the centre of the manhole. In town work every manhole which is frequently used is provided with a small galvanized iron ladder hooked to the framework of the opening. Construction gangs carry a similar type of ladder for use in entering manholes not so provided. Racks for the support of cables around manholes are always fitted to the side walls during the construction of the manhole. Hangers (cable rack hooks) are not fixed until the cables are installed. The general arrangement of a typical manhole is shown in Fig. 17. This figure also shows

the way in which the cables are taken round the walls. The joints are alternately staggered where it is not possible to centre-rack, as indicated. Distribution pipes are terminated in a small pocket on either side, to

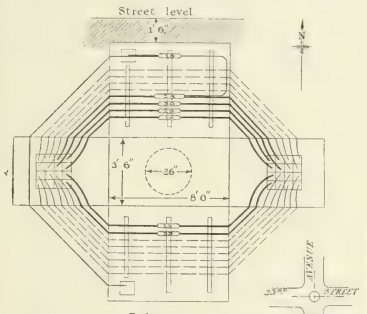

FIG. 18.—Example of cable manhole record.

prevent the cable from becoming kinked at the point where it enters the pipe.

A diagrammatic sketch (see Fig. 18) is made, as an

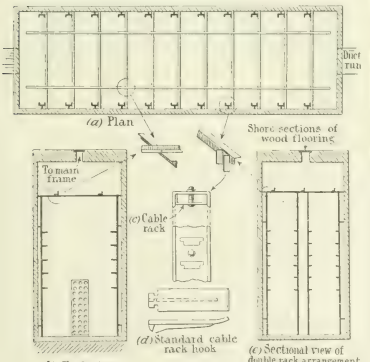
Duct run
(a) Plan
Shore sections of wood flooring
To main frame
(c) Cable rack
(d) Standard cable rack hook
(b) End view
(c) Sectional view of double rack arrangement adopted in large exchanges

FIG. 19.—Cable vault at exchange.

office record, of each manhole at the time of its construction. The cables which are proposed in plans for future growth are indicated on manhole records by dotted lines, so that no error is made when the various ducts are assigned for new cables. By the exercise of foresight in planning manhole sizes for the ultimate cabling, and by utilizing the walls solely for carrying racks and cables, there is not the congestion in manholes which might be expected in the heaviest parts of New York, where as many as 70 or 80 cables are accommodated.

The standard size of manhole used for the accommodation of loading coils is 17 ft. long by 8 ft. wide and 7 ft. deep. In special cases manholes are from 35 to 40 ft. in length. In the longer ones two or even three covers are fitted with means for lighting and ventilation. If local conditions permit, double-deck manholes are constructed in which the loading-coil pots are accommodated below an iron grating, which constitutes a mezzanine floor.

(*c*) *Cable vault at exchanges.*—At the point of entry to an exchange the conduits are terminated at the building line, and from this point cables and joints are supported by a system of racks and hangers. The arrangement is a repetition of the method used for the support of cables in manholes, and provides a very flexible system. Fig. 19 (*a*) shows one method of leading-in, suitable for exchanges to take up to 10 000 lines.

Where cables for two or more 10 000-line unit switchboards must be accommodated in the same vault, a double (or even treble) tier of racks is constructed down the centre of the room as shown in Fig. 19 (*c*). The leading-in arrangement there given appears to form an excellent solution to a problem which has exercised the minds of telephone engineers for many years.

(4) Underground Cables.

(*a*) *Installation of cable in ducts.*—A motor truck fitted with a power-driven winch is used by the telephone companies for the installation of underground cables. It is described more fully in Section VII. The temporary arrangement of gear at the hauling manhole is as shown in Fig. 20. The fixing of the gear and the hauling operations are simplified by the fact, previously mentioned, that in practically all cases the manhole opening is situated over the centre of the manhole. Complicated gear varying with different manholes is thereby avoided. As cables in manholes are all supported from racks fixed to the side walls, they offer no obstruction to cable-drawing operations or the associated gear. In order to avoid moving the truck to each successive manhole, drums of cable are delivered in pairs at alternate manholes. A further advantage derived from this method of working is that the jacks, spindle, etc., available at one point serve for two drums of cable. For country work the gear is conveyed from one manhole to another by means of a small box van, which is also used for drawing out the galvanized iron wire which hauls in the $\frac{5}{8}$-inch steel wire rope. The back wheel of the van is jacked up, and when the engine is started the rotation of a small drum clamped to the spokes of the near wheel withdraws the wire from the conduit and coils it up.

In city work a small petrol-driven engine is used for drawing out the galvanized iron wire in the two directions. A woven-wire grip is placed on the end of the cable after it has been dressed down for pulling in. If

circumstances indicate that hauling is likely to be heavy the grip is reinforced about half-way along its length by a short section of galvanized iron wire, wrapped basket-fashion in and out and beyond the grip along the cable for a distance of 6 inches. The

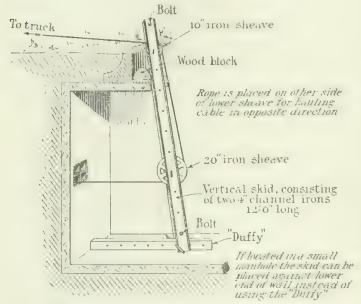
Bolt
To truck
10" iron sheave
Wood block
Rope is placed on other side of lower sheave for hauling cable in opposite direction
20" iron sheave
Vertical skid, consisting of two 4" channel irons 12'0" long
Bolt
"Duffy"
If hoisted in a small manhole the skid can be placed against lower end of wall instead of using the "Duffy"

FIG. 20.—"Rigging-up" in manhole.

adoption of this precaution ensures the wire grip being firmly attached to the cable, and prevents any possibility of the cable end being pulled off, or the lead stretching.

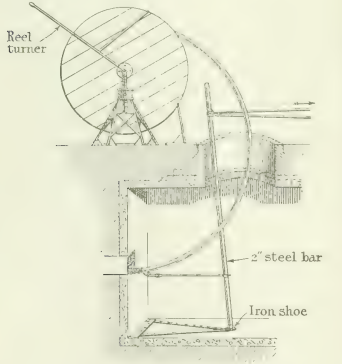

FIG. 21.—Withdrawal of cable; pumping-out method.

A thick motor oil or a graphite grease is used as a lubricant for the cable during installation. American engineers consider that no kind of lubricant forms an effective preservative against chemical or electrolytic action on the lead sheath.

Before the cable placers leave a manhole, the cable ends are tied to hooks fitted in the cable racks, and metal duct shields are inserted under the cable at the mouth of the duct. Men employed in cable installation are carefully drilled in particular operations, and they co-operate so well that, with the aid of the motor truck and other devices, the speed of drawing-in cable has been increased to at least five times that previously attained. The record length of cable drawn into a duct in one day under ideal country conditions is a total of 4 miles of full-size cable contained on 44 drums. In this particular case 20 men were employed for 10 hours and performed the complete work of installation, excluding the delivery of cable to the site and the collection of empty drums.

(*b*) *Withdrawal of cable.*—If a motor truck is used to pull out cable, the wire rope is passed over the sheaves, as for pulling in. A double-ended wire grip, servage of soft marline or unstranded manilla rope, is used as a grip. The extent of each motion is regulated by the

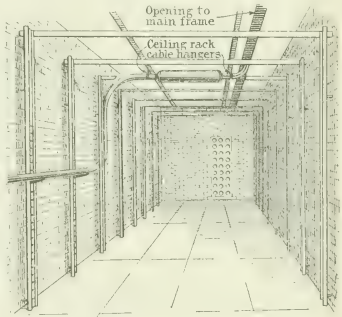

FIG. 22.—Installation of cable in cable vault.

distance between the lower sheave and the end of the duct, the grip being pushed back by hand at each pull. This operation is known as "luffing." When cable is pulled out by hand, the "pumping-out" method shown in Fig. 21 is adopted. It is a very quick and effective process if the man slipping back the grip and those giving attention at the rope and drum work in unison.

(*c*) *Installation of cable at exchange.*—The general lay-out of cables in the exchange cable vault is shown in Fig. 19. If the main frame is situated on the ground floor of the building, the joint between the underground dry-core cable and the terminating cable (known as the "tip") is made in the cable vault in the basement. In such circumstances a long opening, extending the full length of, and immediately beneath, the main frame is provided in the floor, and through this gap the terminating cables are led direct to the main frame equipment. The underground cable is continued along hangers fitted in the racks to a point adjacent to

where it will be terminated. The cable is taken up the wall in supporting clips to the point where it is left for the jointer.

Fig. 22 shows a cable with its joint in position. The space between the racks and wall is sufficient to allow cables to be taken from the hangers of one rack and up the wall to the tie bars or ceiling racks without fouling the run of other cables. Hangers can be supplied to carry two or three cables, as may be required. If the main frame is accommodated above the ground floor, the joint between the underground cable and its terminating cables is situated in a suitable trench immediately behind the main frame; with this arrangement the underground cable is extended beyond the vault through a duct in the vertical wall of the building to the point required. A length of 6 000-lb. suspension

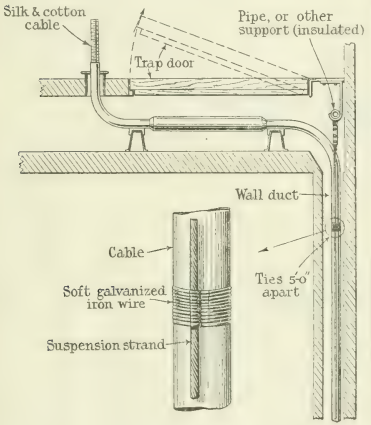

FIG. 23.—Support of cable in vertical pipe and type of joint at back of main frame.

strand is used to support the cable in the vertical duct. The upper end of the strand is terminated on the framework of the building, or on a suitable support installed for the purpose. If the framework of the building be used, the suspension strand is electrically insulated therefrom.

The strands of the suspension wire are forced apart by means of a steel punch, and several turns of No. 18 B.W.G. galvanized soft iron wire are passed between the strands and round the cable. A cable with its supporting strand is either lowered from the main frame floor or pulled upwards from the cable vault, according to local conditions. Fig. 23 shows the upper end of the cable, and a completed tie. When the main frame is located on one of the higher floors of a large building, it is often necessary to take cables through as many as 20 or more floors. Without some suitable method of supporting cables, such as the one described, the weight would impose a serious strain on the lead sheath.

(*d*) *Preliminary work for jointing cables.*—After setting the cables in position for jointing, and removing the lead sheath for the required distance, a piece of cotton tape freshly boiled-out in paraffin wax is wrapped tightly round the core at the edge of the sheath. The tape is worked back between the sheath and the core for about $\frac{1}{2}$ inch, in order to prevent the paper insulation being cut at the point of subsequent bending.

(*e*) *Boiling-out cable ends and joints.*—Before wire jointing is commenced the bared ends of all telephone dry-core cables are boiled-out with paraffin wax at a temperature of about 375° F. The object in view is to preclude absorption by the paper insulation of moisture from the atmosphere, from the jointers' hands, or from any other source. The apparatus used for the boiling-

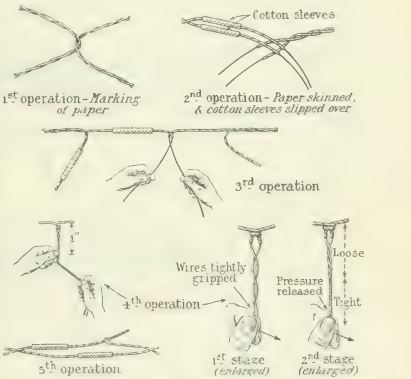

FIG. 24.—Method of making twisted wire joint on small conductors.

out of cables consists of a 4-gallon steel kettle, a ladle, a drip pan, and a paraffin furnace. Molten wax is ladled from the kettle and poured over the end of the cable or joint, and the surplus is received in the drip pan which is suspended directly beneath. A small hole is provided near the rim at one corner of the drip pan to allow the wax to be easily poured into the kettle.

It is specified that paraffin wax must not be heated within 10 ft. of any manhole. This precaution is taken on account of the possible presence of explosive gas. The operation of waxing has never been considered to be at all hazardous if reasonable precautions are taken when carrying the pot from furnace to manhole and lowering it to the jointer. There have been very few cases of injury from this cause. Upon completion of jointing, boiling-out is again performed in order to expel moisture from the joint before plumbing is com-

menced. The specified minimum insulation is 500 megohms per mile, but by the process of boiling-out the insulation obtained in practice is usually much in excess of this figure. The materials required in the process of jointing—cotton tape, muslin and cotton sleeving—are also boiled-out in heated paraffin wax before being used.

(*f*) *Wire jointing.*—A twisted joint is made on conductors up to and including No. 14 B. & S. (65 lb.). For larger conductors, a soldered copper sleeve joint is used. The twisted joints are not soldered in cables for exchange subscribers, but soldering is considered necessary for toll cable circuits in order to avoid any possibility of resistance unbalance which may adversely affect the transmission efficiency of the circuit. The "crank-handle" method of twisting is adopted by all jointers; it is much quicker; there is less chance of the formation of high-resistance joints; and it is also less fatiguing to the men than the finger-twist method. Successive operations in the process of making joints by this method cable or the branch cable to which it is connected are separated and insulated until required, an arrangement usually referred to as a "butt" splice.

Cotton sleeves for insulating wire joints are used in preference to paper sleeves, as it is considered they are not so liable to char during the boiling-out process. They can be boiled-out several times without injury; the joint may be bound in closer; and in trunk cable work it is not necessary to tie the four sleeves of a quad on either side to prevent their displacement during subsequent movement. The cotton sleeves are woven, and after they have been boiled-out a brass sleeve-punch is used to render them cylindrical. When they have been placed in position over a wire joint they are stretched and at the same time flattened at the ends by the thumb and finger of each hand, so that the sleeve grips the paper insulation. After the joint has been made and boiled-out it is bound with 4-inch muslin strip preparatory to plumbing. The muslin is more quickly applied than 2-inch linen tape, and is cheaper.

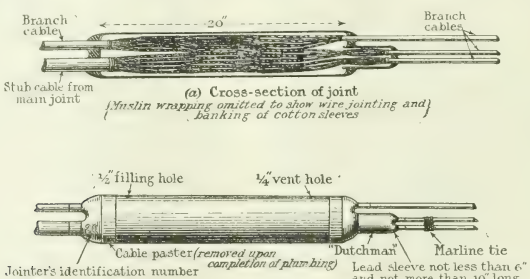
Branch cable
20"
Branch cables
Stub cable from main joint
(a) Cross-section of joint
(Muslin wrapping omitted to show wire jointing and banking of cotton sleeves)
½" filling hole
¼" vent hole
Cable paster (removed upon completion of plumbing)
"Dutchman"
Marline tie
Jointer's identification number
Lead sleeve not less than 6" and not more than 10" long
(b) Finished joint

FIG. 25.—Method of making stub cable joint.

are shown in Fig. 24. There is no possibility of breaking off the wires at the neck if the twist be run in from the fingers of the left hand. The close twisting necessary to avoid high resistances is at the pigtail end, whilst at the neck the wires are comparatively loosely twisted. It should be mentioned that this crank-handle joint is not the same type of joint as that formerly known in this country as the "organ-barrel" twist. In the latter method of jointing, the wires are grasped at the neck and, consequently, there is a danger of the wire being broken at this point; it is, therefore, a dangerous type of joint to make, particularly with the small gauges of copper wire now in vogue. Jointers use scissors during jointing operations, as they are more easily handled than pliers.

When making a stub joint the wires from the two main cables and the wire of the stub cable are twisted together in one joint, known as a "bridge" splice. The stub cable is taken from the main joint to an adjoining rack, where it is then available for distribution to the branch cables. Wires at the end of the stub

(*g*) *Plumbing.*—As all the jointers are fully-qualified plumbers they are able to proceed with the plumbing work as soon as jointing is completed. The cleaned portion of the lead sleeve and sheath is covered with stearine in order to keep the scraped surface bright and clean. Stearine also acts as a flux for plumbers' metal. Cable pasters are used in preference to plumbers' "soil" for limiting the extent of the wipe at the end of a lead sleeve. Complicated plumbing is usually avoided in main joints by the use of stub cables, as shown in Fig. 25.

The maximum length of lead sleeve used on any size of joint is 20 inches. In general, the maximum number of cables entering a wipe is two. If three cables have to be connected at the same place, what is known as a "dutchman" is made; that is, a short piece of lead sleeve is interposed, into which two cables can be taken. It is considered that, if more than two cables are taken into the same wipe, there is a possibility of the joint breaking down. Moreover, a blow-lamp would be required, and a jointer's tool-kit does not include this

item, on account of the danger of using a naked light in a manhole. For the same reason, electric lamps in conjunction with portable accumulators are used for the illumination of manholes.

As an additional safeguard against the rapid penetration of moisture into a Y joint the latter is filled with paraffin wax. After the wipes have set, but before the sleeve has cooled, a small hole is made at each end of the sleeve, one being used as a filling hole and the other as a vent. Heated wax is poured in until the joint is full. Straight joints are not filled with paraffin wax. The jointer stamps one of the wipes with his code number, and ties on to the cable a small brass disc bearing the number which has been assigned to it. Upon the completion of plumbing work cables are dressed into their final position on the walls, where they remain undisturbed.

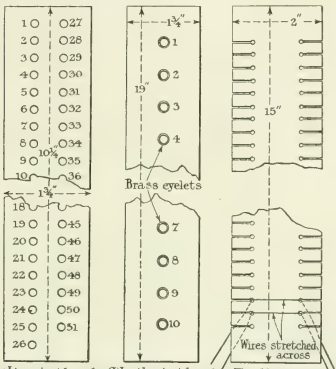

FIG. 26.—Jointers' test-boards.

(*h*) *Speed of jointing.*—By the adoption of the various devices mentioned in the foregoing paragraphs the jointers are able to work at a rate of over 100 pairs an hour on a subscribers' cable. The more experienced men can joint as many as 150 pairs an hour, with the result that it is often possible to complete a 600-pair, 10-lb. cable joint in an 8-hour day.

(*i*) *Bonding.*—Owing to the trouble caused by electrolysis, all cables in manholes or jointing chambers are bonded together by means of tinned copper ribbon. It is not customary, however, to sink earth plates under the floors of manholes; as experience has shown that connections made by bonding ribbon between the earth plates and cable is not reliable. Periodical tests of leakage current between cable sheath and earth are made. If certain limits are exceeded immediate steps are taken to localize the trouble and apply a remedy.

(*j*) *Numbering and testing.*—For tagging-out conductors in an exchange subscribers' cable when making test-joints, or for numbering-through purposes, a "linen test-board" [see Fig. 26 (*a*)] is used, in preference to a numbered paper sleeve.

In re-numbering cable pairs, e.g. in connection with an exchange transfer, this board is very useful, as the stamped number can be considered as the old number, and the new number can be written on the reverse side, thus avoiding confusion between the two.

When working on a quadded cable a leather board is used. After the quads have been placed through the holes the pairs are separated. As there is no means of distinguishing between the "a" and "b" wires one of the wires is cut three inches shorter than the other. The wires are then referred to as "long" and "short," and recorded on the testing sheets as L and S. When testing a large working cable of small-gauge conductors in connection with a section throw (change-over), a flexible leather strip is used, as shown in Fig. 26 (*c*). Current is applied to one of the wires at the distant end, and this is picked up very quickly at the strip by running the testing lead over the exposed wire.

(*k*) *Jointing-in loading coils.*—If loading coils are installed immediately below the cables, either by being embedded in the ground or placed under the mezzanine floor of a double-deck manhole, the stubs from the loading coils may be taken direct into the main joints. Only one stub per pot is provided, and wherever possible

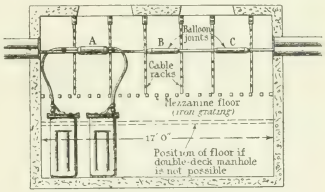

FIG. 27.—Installation of loading coils in double-deck manhole.

not more than two stubs are taken into the same joint. Where all the pots are not installed initially, a so-called "balloon" joint is made at the points where the later loading-coil stubs will be connected to the main cable. In Fig. 27 two loading-coil stub cables are shown connected up at the joint A, whereas B and C are "balloon" joints.

The method of making a "balloon" joint is as follows: Before the joint A is made two 20-inch lead sleeves are slipped over the cable sheath, and a 12-inch ring of sheath is removed at the points B and C. The wires thus exposed are doubled back over themselves so that there is about 6 inches of slack in the conductor at each point. The lead sleeves are drawn over, and wiped joints are made until such time as the additional loading coils are installed. By making the "balloon" joint, slack will then be available for jointing-in the stubs subsequently, without having to piece out the

whole of the wires. Where it is not possible to install the loading coil pots in the same manhole as that in which the cables are jointed, an auxiliary loading-coil stub is provided.

(*l*) *Pressure-testing.*—In general, desiccators are not employed by telephone companies in America; but there are one or two companies which use a desiccator in conjunction with an air compressor, merely to test the integrity of the lead sheath between one jointing point and another after installation, and also to prove that the plumbers' wipes are sound. It is generally considered that the cost of making pressure-tests on subscribers' cables is not justified, as the number of failures experienced is so small. The cable sheath is assumed to be intact when it leaves the works, and every care is taken to avoid any abrasion of the sheath during installation. Every man learns the technique of plumbing in the company's training school, and must prove adept before he is employed on actual work; consequently the quality of the plumbing is remarkably good. The men take a pride in their work, and a cable failure resulting from a plumbing defect is regarded as such a reflection upon workmanship that it very seldom occurs.

In the case of long-distance cables the question of pressure-testing is somewhat different, since, if an undetected fault were to occur during installation, the expense of remedy would be considerably more than in towns, where a large maintenance staff is available. The disturbing effect on trunk service is also of greater moment. The author believes that the question of pressure-testing long-distance cables is now under consideration in America.

(*m*) *Desiccation.*—No attempt is made to remedy insulation breakdown by desiccation, either by means of dry air or by carbon-dioxide. The opinion held is that, if the initial construction work be carried out satisfactorily, there is no reason why a fault should develop between one jointing point and another, apart from the comparatively rare case of mechanical injury or chemical and electrolytic action. A breakdown from either of these causes would probably involve the complete replacement of the cable, unless the fault were of a purely local character, in which case the section could be boiled-out with paraffin wax. Cables are so carefully racked when placed in their permanent position in manholes that there is little chance of any injury to the joints.

Although the wax left in the sleeve does not constitute a solid joint, it has the effect, in the remote event of a defect occurring, of delaying the advance of water into the cable and so preventing serious damage before the fault is likely to be discovered. The boiling-out system results in a high insulation-resistance, and, if moisture does enter a joint later on, a process of re-boiling is depended upon to restore normal insulation. If water has penetrated too far for re-boiling to be effectual, the cable is replaced without further delay—an operation which is, however, seldom necessary in practice.

(*n*) *Types of joint.*—The differences between the various types of joint in use in America may be mentioned here with advantage, in order to elucidate their respective features and uses:—

(i) The boiled-out joint is *not* solid. Wax at the temperature specified runs through the open joint like water, the practice being adopted merely to avoid low insulation. The quantity of wax remaining in the joint is very small, and the free passage of air is not impeded if a pressure-test is at any time required.

(ii) A **Y** joint filled with wax is also not solid in the true sense of the word. Probably a sustained pressure-test could not be made, but the joint would serve as a fairly effective block to the passage of air, and, if the plumbing were defective, water would take an appreciable time to penetrate into the cable.

(iii) The pot-heads formerly used for terminating paper-insulated lead-covered cable in some of the cable terminal boxes are *practically* solid, as a black insulating compound is used, with the object of preventing moisture creeping along the rubber leads to the paper cable.

(iv) In submarine cable work, where paper-insulated cables are used, joints are required which will *absolutely* prevent moisture getting to the cable. Such joints are made on a principle entirely different from that of merely filling with compound, even under pressure, as there is always the possibility of water penetrating the cable owing to the contraction of the compound.

(*o*) *Terminating cable.*—At exchanges, paper-insulated cable for subscribers' lines is terminated by means of short lengths of double-silk and single-cotton-insulated lead-sheath cable. The conductors are of 10-lb. tinned copper wire. Terminating cables range in size up to 600 pairs, the type chosen being dependent upon (1) the size of the cable to be terminated; (2) whether there is a mezzanine platform; and (3) the number of pairs accommodated per vertical of the main frame. Where three or four of these terminating cables have to be jointed to a main underground cable, a standard type of joint is adopted, using one or two "dutchmen" as illustrated in Fig. 25. In the termination of a toll cable double-silk and double-cotton-insulated wire in quad formation is used. Joints in exchanges for either subscribers' cables or toll cables are not filled with paraffin wax or other impregnating material.

(*p*) *Cross-connecting points.*—Throughout the Bell System the standard practice is to determine the best arrangement of distribution of wires to serve for the development period, and to joint them through direct, enclosing the joint in a lead sleeve. If construction work is ably carried out in the first instance there is little likelihood of maintenance trouble arising at such points. If after two or three years it is found that the original distribution of the circuits requires modification, it is a comparatively simple matter to open the stub cable and re-arrange the circuits for a further period. This method avoids repeated interference with the cable wires at junction points and other places along the line of cable; a practice which is always subject to abuse.

(5) House Cabling.

In large hotels and office buildings where the demand for telephone service is on an extensive scale, arrangements are made for the initial installation of a complete cabling system carefully designed to meet the ultimate requirements of the building. The class of service required for hotels is somewhat different from that demanded by large office buildings, and the difference markedly affects the design of the cabling scheme.

(*a*) *Hotels.*—The number of telephones for hotels can be determined with fair accuracy, as practically every room (in some cases as many as 2 500) is fitted with a telephone. Consequently the cable system can be laid out in advance on a permanent basis. Hotel telephone service is handled by means of a private branch exchange switchboard, located at some convenient point. All circuits, with the exception of junction lines, radiate from the exchange to distribution centres situated on the various floors. There are two general types of distribution in vogue, one in which the main cables (known as "riser" cables) are installed in a shaft with branch cables on each respective floor, and the other in which the cables are installed in conduits, small boxes being provided to accommodate the joints. The riser cables are attached to suspension strand wire, as in the case of exchange cables. It is not considered economical to open the riser cable at each floor, and therefore the cables are diminished at every third and fourth floor. From the diminishing points branch cables are taken to the floors above and below, and thence to distribution centres, where they are ended in terminal boxes suitably situated for the connection of the individual telephone wires.

The terminal box for internal distribution normally consists of a block of insulating material carrying a number of binding posts and a fanning strip which serves as a guide to preserve the arrangements of the individual twisted pairs. The posts and strips are mounted in a wooden box which can be fixed to the surface of the wall, or recessed into the wall if the installation work can be carried out before the building operations have been completed. Accommodation for wires from terminal boxes to the telephone instruments is afforded either by small conduits or by suitable mouldings along the walls of corridors and rooms.

Frequently the required lengths of cable are cut and the necessary jointing to branch cables or stubs carried out in a central workshop, instead of on site. There is much to commend this method, as the work is done in a better manner under workshop conditions, particularly when the cable has to be installed in a vertical shaft. The arrangement also provides work for elderly or partially-disabled jointers, whose services could not otherwise be retained. If the cable cannot be formed into a small coil suitable for transport to the site it is placed on a drum with the joints securely tied to prevent fracture due to bending close to the joints. The equipment of terminal boxes is also frequently completed in the workshop, in which case the only work remaining to be done on the site is a straight joint between the two cables provided. In damp situations silk and cotton-covered wire forms, boiled out in pot-head compound and painted with moisture-proof paint, are used, and the terminals are of metal instead of wood, unless local circumstances permit the use of the No. 14 external type of terminal.

(*b*) *Office buildings.*—In large office buildings arrangements vary considerably, according to the requirements of individual tenants. Some require a large number of out-going lines, with little or no internal service, while others desire branch exchanges with a large number of internal extension lines. A system of cabling sufficiently flexible to meet these conditions is arranged for by providing a distribution case or cross-connecting frame at some convenient point, usually in the basement. A certain number of the circuits in the main cables from the exchange, known as "feeder cable pairs," are jointed to the pairs in the riser cables; they therefore terminate direct on the terminal boxes, whilst

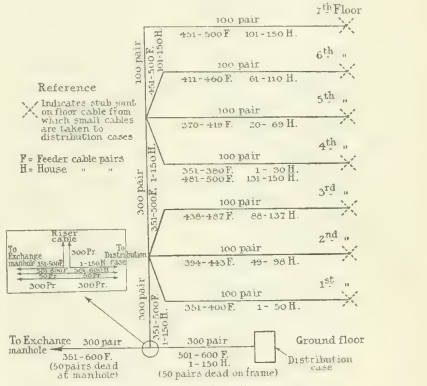

FIG. 28.—House cabling diagram.

the remainder of the wires in the main cable are taken to the frame. The remainder of the circuits in the riser cables, known as "house cable pairs," are brought to the connecting frame. Fig. 28 shows a small wiring diagram which illustrates the system.

From a maintenance point of view this arrangement is decidedly advantageous; it also avoids crowding the connecting frame with unnecessary circuits. By carefully arranging the number of pairs in the relative groups, a very flexible system of distribution, which enables additional exchange facilities and internal extensions to be afforded without delay, is obtained. In one large office building in New York, containing about one million square feet of renting area, four main cables, each of 900 pairs, are brought in from the neighbouring exchange; approximately 600 pairs in each cable are taken direct to the riser cables; and the remaining 300 pairs are taken to the connecting frame, which is similar to the intermediate distribution frame

of a large telephone exchange. There are several 600-pair riser cables serving the 22 floors of the building. This gives an idea of the magnitude of some house cabling lay-outs, the working plans for which are exceedingly complicated.

The distribution of the wires to terminals is arranged on the bridging or multipling system, i.e. one pair of wires is available for use on more than one floor. This increases the flexibility of the system, and fewer spares are required than if there were no multipling. The method of distribution from the wiring centres is practically the same as in hotels, unless there are private branch exchanges, in which case a lead-covered cable of suitable size is taken from the feeder cable direct to the switchboard concerned.

(6) Block Cabling and Wiring.

The advantages of the American "block" system, from a distribution point of view, were briefly mentioned under

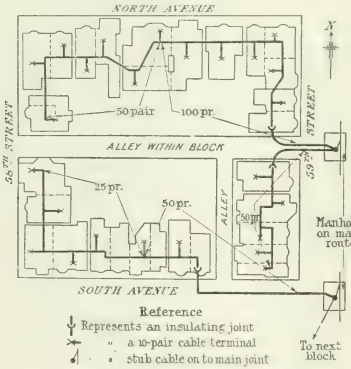

FIG. 29.—Block cabling (internal).

Section IV (Design and Lay-out). Where the telephone density is not sufficient to justify internal house cabling schemes, and is greater than could be served economically by a pole route, a system of block cabling is adopted. A branch cable from either an aerial or underground exchange cable is taken to some suitable point in the block, from which distribution can be made. If the buildings are continuous, cables are usually taken along the walls externally, with cable terminals fitted at intervals convenient for distribution. Cable clamps secured by means of wood screws are used for attaching cables to the walls of buildings. Holes are drilled in the centre of the bricks, and expansion shields are fitted to take the screws. All clamps are tapped to receive a bridle ring in case the latter is required for bridle-wire distribution. Where buildings are not continuous an aerial span must be introduced, suspension strand and cable rings being utilized, as described in Section V (2). If, however, the distance does not exceed 15 ft., a short piece of iron pipe is let into the brickwork on either side. The cable is secured to this pipe by wrappings of soft galvanized iron wire. Where outlying buildings or other obstructions prevent a clear run on the face of the building, cables are frequently conveyed through the basements.

Fig. 29 shows a typical block consisting mainly of large apartment houses. Owing to the irregularity of the buildings, block cables are run internally through the basements. This type of house has usually a very good basement, on account of the furnaces required for the central-heating system. If there is a break in the continuity of the buildings the gap is bridged by means of a piece of iron pipe laid in the ground, through which the cable is drawn.

From a maintenance point of view the use of wood or iron fences for block cabling is discouraged.

For distributing purposes the No. 14 type of cable terminal is almost invariably used. Cable terminals can be obtained with tail pieces entering the terminal from the top or bottom, according to the position in which they are to be fixed, but, wherever possible, terminals are so placed that they are accessible to workmen without the aid of ladders. In that case the cable usually enters the terminal from above. Cable terminals are provided at frequent intervals, and circuits are multipled to two or more terminals in order to provide flexibility. Bridle wire led through bridle rings is utilized for connection to subscribers' telephones. Bridle wire consists of two No. 18 B. & S. gauge tinned copper wires, insulated with rubber compound, covered with black weatherproof braid and twisted into a pair. To avoid confusion it should be mentioned that the terms "bridle wire" and "drop wire" are not synonymous. Bridle wire is not self-supporting and is intended only for use in bridle rings for block wiring and on poles for cross-connections. When more than six bridle wires are likely to be required on any run, the advisability of installing a cable is considered.

In the case of apartments or flats, generally four or five stories in height, bridle wires are frequently taken up dumb-waiter shafts to the floor required, thus avoiding ladder work.

One advantage which the telephone companies have from a plant-record point of view is that the fire insurance companies issue a large scaled set of plans for each town, showing each block in detail. To some extent a similar type of plan is available in this and other countries. The type and class of each building (e.g. brick, wood, number of floors, etc.) are clearly indicated. In return for a small annual subscription the insurance companies are willing to keep these maps up to date. Plant details can be recorded on these maps, so that any new order received for telephone connection can be at once localized and definite instructions given to the installation men without an actual survey being made.

Block cabling represents an exceedingly flexible system, and, after completion of the main scheme, telephone service can be readily supplied to any house in the block at small cost.

(7) Drop Wiring.

Reference was made under Section V (1) to the use of covered wire, known as "drop wiring," for distribution from pole routes to subscribers' premises. It plays such an important part in distribution that further mention of the system is desirable. Several stages in the development of distribution methods have been traversed since the days when distribution was effected by means of large numbers of open wires supported upon high poles. Now the standard method is to erect short poles (20 to 24 ft.) in the alleys within blocks or in the roadways; from these poles covered drop-wires are run direct to the subscribers' premises.

In "thin" areas, where the telephone density does not justify external or internal block cabling and wiring, a carefully-designed aerial cable system, liberally provided with cable terminals, forms an economical system of distribution. It is far more effective than the provision of a few distribution poles connected direct to underground cables. Plant of this type is neat and inconspicuous, and does not raise any objections on æsthetic grounds, with the result that the necessity for underground work may remain dormant for many years. At one time the underlying principle was that cables should be tapped as little as possible, but to-day there is nothing to be feared from a multiplicity of cable terminals which makes possible a system of covered drop-wire distribution.

The terminal is a vital part of the distribution system; therefore it has been carefully and substantially designed. Types Nos. 8 and 14 are now used exclusively. As their cost is only a small part of the total expense, there has been no temptation to sacrifice efficiency for cheapness.

The number of opening-out points depends upon the density of the subscribers' lines, but a liberal use of terminals is favoured in order to avoid running covered wires parallel with the main cable. Speaking generally, a terminal is used if 300 ft. of drop-wire will thereby be saved. Hence if it is expected that three subscribers' lines will radiate from each pole, a terminal is fitted initially on each pole, or at least on each alternate pole.

In addition to the factor of annual cost, another important element enters into the question of terminal *versus* drop-wire, viz. the number of men engaged and the time spent on installing the subscribers' lines. By the generous provision of terminals the size of the gang is reduced to a minimum. One man, with an assistant, can complete a drop-wire installation in a surprisingly short time, as all that is required is to tap a cable terminal at the front or back of the subscribers' premises and connect the lead thereto. Each drop-wire gang is usually supplied with a small motor van which carries all the materials and tools likely to be required. Such a gang can install, on the average, 8 to 10 lines in an 8-hour day.

No attempt is made to taper short lengths of distribution cable. It is claimed that such cable—usually 50-pair—must be regarded as similar to a gas or water main; something to be tapped for a subscriber's circuit at any point along its length. An 11- or 16-pair cable terminal is the usual size fitted, and some of the circuits are made available at two or more terminals in order to increase flexibility and avoid subsequent changes in arrangement of circuits.

The use of a large number of small cable terminals reduces the length of the subscribers' loop to a minimum. The policy of employing drop-wire of high-grade material has been adopted. The type now employed has a normal life of at least 10 years, and is used over and over again. When recovered, drop-wire is sent to the stores and is examined, the bad pieces are cut out, and the remainder is re-jointed ready for re-issue.

Drop-wires are terminated on small porcelain "knobs" which are carried by small rectangular galvanized brackets. The latter are attached either directly to the pole or to the guard-arm fitted on a joint-use pole. They carry one or two knobs and drop-wires

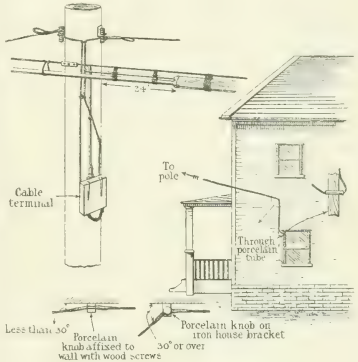

Fig. 30.—Drop wiring.

as required. A similar galvanized bracket is fixed on the subscriber's premises, and a direct lead into the building is then generally obtained, as shown in Fig. 30. If this arrangement is inconvenient, an additional bracket is fitted, or the drop-wire is taken along the face of the building in small bridle rings. A porcelain tube is inserted at the point of entrance to the building. A termination of this description is jointless, as it is taken direct from the cable terminal by way of the pole bracket and the house bracket to the window block fitted inside the subscriber's premises. It has a great advantage over open-wire distribution, where at least two changes are made—from cable to open wire, and from open wire to leading-in cable—and where cross-connecting may be necessary if the wires are brought from the end of the arm.

The advantages claimed for this drop-wiring method of distribution may be briefly summarized :—

(1) Short poles may be used, as foliage and other

obstructions do not affect covered drop-wires in the same way as they would open wires.

(2) Pole arms are not required, and the system of brackets and insulators involves the minimum of material.

(3) There is less danger of contact with high-tension wires.

(4) Short-circuits and contacts are avoided, and therefore maintenance costs and interruptions to service are reduced.

(5) The subscriber's loop between the terminal and the subscriber's premises is free from joints.

(6) The possibility of "humming" is lessened.

(7) Induction effects are reduced, as the wires are perfectly transposed.

(8) Telephone service can be supplied at short notice.

(9) The cost of running individual circuits after the main scheme has been completed is small.

In regard to (4) it might be mentioned that the last span of open wire is always a source of many faults; in fact, it has invariably more than a proportionate number of faults.

SECTION VI.

Transport.

Motor transport is much more largely used on telephone work in America than in England for the following reasons:—

(*a*) The initial cost of trucks and cars is less.

(*b*) Petrol is retailed at about one-third the British price.

(*c*) Greater distances have to be covered.

(*d*) Construction and maintenance hands are paid at very high rates.

(*e*) It is difficult to obtain convenient accommodation in country districts.

Under the conditions existing in America, in fact, it is a comparatively simple matter to prove economy by the use of motor transport. In country work, instead of construction hands camping out, arrangements are frequently made to board them at the nearest village, from which they are conveyed to the site of work each day. Three-ton trucks are used for this purpose and also for the transport of small bodies of workmen, tools, and materials from one point to another during the course of the day.

Each gang foreman, who may control from 10 to 20 men, is usually supplied with a two-seater car, fitted with a box body. This enables him to supervise the work closely, and also to convey the small stores which may be required. Motor cycles are used to a limited extent for maintenance purposes, but not on construction work, for which they are not considered reliable or adaptable.

As will be seen from the lantern slides, the truck used by an overhead construction gang is fitted up as a travelling store-room. Along the two sides of the truck small partitions are provided for carrying the stocks of bolts, insulators, screws, etc., which are required for a large job. The necessity for issuing small quantities from the main stores during the progress of the work is thus avoided. The truck is also designed to carry ladders, ropes, tree-cutters and other gear. A first-aid box is carried on every gang truck.

The amount of "dead time" on construction work has been greatly reduced through the use of these trucks. Even in town work they are most useful, as they convey men and stores direct to the site of operations in the shortest space of time.

The great use made of transport by the telephone companies has necessitated the building of large garages and the employment of a special staff of men for dealing with repairs. The New York Telephone Company, for instance, has a fleet of over 1 000 vehicles of various descriptions, and a staff of 250 engaged on maintenance and repairs. Nevertheless, the companies are satisfied that such expense is fully justified by the resulting improvement in efficiency.

SECTION VII.

Mechanical and Labour-saving Devices.

The high rates of pay in America have necessitated the use of many labour-saving appliances. Owing to the large increase in wages in this country during the past five or six years, the following particulars of some of the machines used may be of interest:—

(*a*) *Excavating machines for trench work.*—A small machine, known as a "ditching machine," particularly useful in excavating the shallow trench required for telephone conduits, has been developed. At the rear of a small traction engine is fitted a wheel about 6 ft. in diameter, which can be lowered at will. The periphery carries several bucket-shaped prongs which penetrate the ground and throw the excavated soil to one side. A trench 19 to 24 inches wide up to a depth of 5½ ft. can be formed by this machine. It is suitable for footway and roadway work where there are not many obstructions. Details of the obstructions are usually ascertained in advance, and the machine can be so controlled that it is stopped within a few inches of any obstacle. The prongs will cut through an ordinary macadam roadway without difficulty, and on country roads a speed of 7 ft. per minute can be attained.

(*b*) *Back fillers.*—A modified form of a farmer's plough is used for pushing the ground back into the trench ready for ramming. Two men are required to guide the plough, which is drawn by the steel wire rope on the winch of a motor truck.

(*c*) *Tamping machines.*—The difficulties of hand-ramming have been overcome by the use of a mechanical tamper. A 12-in. square block weighing 150 lb. is elevated 4 ft. by gearing driven by a small petrol engine, and then released. Thirty blows a minute can be delivered whilst the machine is travelling horizontally at 3 ft. per minute. This machine can do as much work as 10 men, each armed with 10-lb. rammers (or punners). To fill in a trench 2 ft. deep the back filler and tamping machine traverse the course twice.

(*d*) *Concrete mixers.*—For laying a concrete foundation, forming the sides or top protection of a conduit route,

or supplying the concrete for manholes, a concrete mixer fitted on a motor truck has been evolved. The gravel and sand are mixed at a yard and raised into hoppers on the truck by means of a small motor-driven conveyer. A tank on the truck is filled with water. When on the job a quantity of the gravel and sand is released from the hoppers and fed into the mixer; cement and water are added and the mixer is rotated by gearing connected with the mixer engine. A movable trough is used to convey the concrete to the trenches or manhole, where it is levelled by hand.

(*e*) *Pole-hole excavators.*—A 3-ton truck is used to carry a large auger capable of making a hole from 18 to 24 inches in diameter up to 6 ft. deep. Power is supplied from the truck motor to various trains of gearing which in turn rotate the auger at the rate of 60 r.p.m. A revolving turntable on the truck permits the hole to be excavated from either side or from the rear of the truck. A pole-hole 6 ft. in depth can be excavated in from 3 to 5 minutes in various types of sub-soil. Clay and even hardpan offer little resistance to the auger—the only serious obstacle being actual rock. The operation of the machine is controlled by two men, one acting as driver, and the other as auger-operator. Manipulation is effected by means of two levers, one for engaging the up-and-down feed, and the other for engaging and disengaging the auger driving clutch. After boring has been continued for some time the auger is raised, bringing with it all the earth excavated. The earth is then quickly dispersed by the rotation of the auger. The latter can be tilted for boring at an angle, as for example, in excavating a stay-hole.

In a more recent type the truck is fitted with a derrick, which is capable of erecting the pole upon completion of the excavation. The author witnessed the erection of 45-ft. poles in a back-alley in Detroit by means of this equipment. In each case the sub-soil was a hard clay, and it took the machine $4\frac{1}{2}$ minutes to bore a 6-ft. hole, and a total of $6\frac{1}{2}$ minutes to place the pole in position ready for tamping. One foreman and two skilled men represented the total gang.

(*f*) *Pole erectors.*—All telephone companies have a certain number of 3-ton trucks fitted with derricks for pole erection. The derrick is normally carried on the side of the truck, but can be placed in position for pole erection in a few minutes. On country roads where the poles are laid out along the road in advance and where the holes have been excavated it is possible to erect 25-ft. poles at the rate of about 40 per hour under favourable conditions. The maximum number erected on an 8-hour day by one foreman and eight men using one 3-ton truck is 300. The same derrick can also be usefully employed for withdrawing the old stump of a pole when replacement is necessary.

(*g*) *Installation of loading coils.*—The 3-ton trucks are fitted with a small type of derrick or shear-legs designed for lowering loading-coil pots into manholes. An alternative method adopted by some of the telephone companies is to fit the truck with an overhead runway, consisting of an H girder which overhangs the rear of the truck. By means of block and tackle the loading-coil pots are lifted off the floor of the truck, run along to the end of the girder, and lowered into the manhole.

(*h*) *Pumps.*—A centrifugal pump, capable of emptying manholes at the rate of 300 gallons per minute, is fitted to trucks used on underground construction or maintenance work. The pump is driven from the engine of the truck.

(*i*) *Motor winch for cable installation.*—The majority of the Bell telephone companies use a power-driven winch fitted on a 3-ton motor truck for the installation of cable. The winch is usually 24 inches between flanges, with a 10-inch barrel, and is fitted immediately behind the driver's cab. It carries about 1 000 ft. of $\frac{5}{8}$-inch steel wire rope for hauling the cable. The winding gear is fitted with an auxiliary clutch box (driven from the truck's transmission gear) and a suitable reduction gear. This truck can also be used for carrying two drums of cable, and the winch is then useful for raising and lowering the cable on the loading ramps. By a simple movement of a single lever the load can be lifted, held, or lowered. The rate for drawing-in cable under normal conditions is about 50 ft. per minute.

(*j*) *Air-driven drilling machines.*—Where rock is encountered during the excavation of trenches for duct work or for pole erection, portable pneumatic drilling machines are frequently used. A $1\frac{1}{2}$-inch hole can be drilled 3 ft. deep in solid rock in from 7 to 8 minutes, after which a charge of dynamite is inserted. The surrounding rock, being thus shattered, can be cleared out by ordinary means.

SECTION VIII.

Maintenance.

Throughout the associated companies in America there appears to be a keen spirit of "Service First," so that the public shall have no legitimate ground for complaint. Under pre-war conditions the time taken for clearing faults in large cities was reduced to an average of about two hours per fault. This was made possible by the concentration of all testing and localizing apparatus in one central office. In New York, for example, there is a central test-office in the southern portion of Manhattan which does all the testing for 20 exchanges, embracing about 260 000 stations, just as if the testing apparatus were located in the apparatus room of each. When a fault is reported the test clerk stationed at the exchange concerned telephones the details to the central test-office and connects the faulty line to a junction between the two offices. Necessary instructions are conveyed by means of loud-speaking telephones fitted at several parts of the apparatus floor of the exchange concerned. If a fault is proved to be outside the exchange, details are passed on to the fault-distribution officer, who is in telephonic communication with all the linesmen. Each large building, block, or group of blocks, is considered for maintenance purposes as a unit under the control of one man. The distribution officer has a large-scale map of the territory on the wall, with a small hook placed in the centre of each maintenance section. A

ticket showing details of each current fault in this section is placed on the hook so that the necessary instructions can be given to the responsible linesman. Instrument faults which cannot be quickly remedied on site are dealt with by changing the instrument, the defective one being handed over to mechanics for repair.

Linesmen are provided with motor cycles or even small cars, when their use can be justified, to enable them to deal with long-distance subscribers' line faults. Toll line routes are divided into sections, and each section linesman has a two-seater Ford car fitted with a small box body, in which can be carried small quantities of any type of line material likely to be required. These section linesmen are also furnished with an exchange telephone at their private residences, so that they may be called out at any time in case of emergency.

Breakdowns of telephone line plant due to heavy sleet storms are now being considerably reduced by the more extended use of cable instead of open wire. As mentioned earlier in the paper, there is little danger of an overhead route being brought down when carrying cable only.

As it is not customary to impose pressure-tests upon completed cable works, or to use desiccators for raising low cable insulation, it might be expected that the maintenance of underground cables suffers in consequence. In practice this is not the case. In the central testing-offices careful records of all faults in underground cables are kept, and, if more than two or three pairs have to be changed over in the same cable for the purpose of clearing faults, suspicion is aroused and the necessary localization tests are at once made with a view to determining the cause of the trouble. In this way incipient faults are generally detected and remedied. The universal practice of boiling-out all cable joints tends to delay a complete cable breakdown from any cause other than mechanical injury.

As a rule the provision of spare conduits is on a liberal scale, and a small stock of each size of cable is usually available in the vicinity of the main routes. The construction gangs are thus able to introduce a new length of cable into a duct adjacent to the one containing the faulty cable and change over the circuits within a few hours of a warning being given.

SECTION IX

Conclusion.

There is one feature which might be emphasized in connection with telephone construction work in the States. When the speed at which the work is carried out was first realized, it was imagined that the quality of the work would necessarily suffer. Investigation showed, however, that this was not the case. There are several reasons for this unexpected combination of high quality and rapid output. The ready acceptance of machinery and labour-saving devices by the working man, and the fact that they have been used to their full capacity, have been conducive to high efficiency. Trade unionism exists to some extent, but there is no desire to hamper output. The men readily accept any suggestion for speeding up the work, as they believe it will be to their advantage to reduce costs; in consequence it has been possible to place the majority of telephone workmen on the staff of the various companies rather than on an hourly basis. They receive a good weekly wage and enjoy privileges in regard to holidays, sickness, pensions, etc., which attract a good class of man. Another important point is the prospect of promotion to the higher grades for all ranks. It is a fact that any position in the Bell System is open to anyone who becomes qualified for it. Amongst the jointers are men who have graduated in a university; they have started at the bottom but are not content to remain there. The actual hours worked are not long, but while the men are on duty they work hard and well.

The author desires to express his thanks to the engineers and superintendents of the American Telephone and Telegraph Company and the New York Telephone Company for supplying information and illustrations and for their permission, subsequently obtained through the Western Electric Company, to make use of such data in this paper. The photographs of various sections of plant work which have been shown upon the screen were presented by the Plant Department of the New York Telephone Company. Reference must also be made to the valuable assistance given by the staff of the Illinois Bell Telephone Company, the Michigan State Telephone Company, and many others.

Discussion at The Institution, 17th November, 1921.

Sir Andrew Ogilvie: The great importance of the author's careful study of American practice in a very important branch of telephone work will be readily agreed. I shall however, confine my remarks to a few points which relate to general administration. The paper states that the A.T. & T. Co. controls 12 million telephone stations. That is the total number of stations which can be reached through the Bell system, but it includes, besides the 8 million stations of the federated Bell companies, about 4 million stations belonging to independent companies which cannot strictly be said to be under the control of the A.T. & T. Co. I do not say this with any desire to disparage the work of that company, because it is an institution for which I have the profoundest admiration. The paper gives a very interesting account of the functional and territorial organization of the Bell companies. It refers also, but not so fully, to the splendid standardizing and research organization which the company maintains at its headquarters. That organization includes some 1 200 real experts in every branch of telephone work, and also, more recently, in telegraph and wireless work, and it is without parallel in the world. These experts are not executive officers; they are purely scientific people who are studying the problems of telephone work arising in the magnificent field of experience in the vast systems of the Bell companies. The paper also calls

attention to a difference between the American and British points of view as to what constitutes an engineer. In this country we include among engineers all those experts who are engaged in construction and maintenance as well as those who are engaged in the study of pure theory. In America that is not the practice, at any rate so far as telephone work is concerned. The title "engineer" is limited to the man who is devoted to abstract study, and it is not applied to any executive officer. In America, too, they include among engineers traffic experts, that is to say, experts in the methods of working the service, and even commercial engineers, experts in the best methods of selling the service to the public and of anticipating public requirements. It is not perhaps a matter of great importance as bearing directly on the subject of the paper, but it is a distinction which is very frequently lost sight of in discussions as to the difference between American and English telephone organization. The paper gives a most interesting account of development studies. These methods are probably familiar to most telephone engineers in this country, because our methods of development study have been based almost entirely on American methods. The extraordinarily rapid growth of American cities and the American telephone system made it very important that, in order to avoid uneconomical construction, there should be forecasts of development for considerable periods ahead. The fact that our methods have so closely followed American methods is due to a very large extent to the liberality which the A.T. & T. Co. have always shown in placing the results of their investigations and studies at the service of British engineers. In the paper there are a good many references to the use of glass insulators. At first sight, perhaps, that does not seem a very important point, but it causes a feeling of envy in the mind of anyone who is accustomed to dealing with telephone questions in this country. Certainly in this country the extensive use of glass insulators and wooden pins would be impracticable. The British climate is infinitely worse, more difficult, and more expensive for telephone work than the American climate. That is probably the chief factor in equalizing the cost of maintenance work in this country, although American wages have been, and will probably continue to be, considerably higher than ours. Another evidence of that superiority of climate seems to me to lie in the free use of loading coils on open lines. That, when I was more actively concerned with telephone work, was a matter of great difficulty, if not of impossibility, in this country. The description given of the methods of laying conduits is most interesting, as showing that American practice is approaching more nearly than formerly to British practice. At the same time, our practice probably has moved in the direction of American practice. I notice that in America desiccators are rarely used for getting rid of dampness in cables. In this country, when the Post Office first started telephone work it was considered that desiccation was the only practicable and useful method. I believe we have moved away a good deal from that position, but still I think it is probable that the difference between our climate and the American climate will always necessitate the extensive use of desiccators. The methods of block cabling described as being in force in American cities also make one feel envious. They show one of the advantages which American practice has over ours. American cities are laid out in blocks; in many cases those blocks have central alley-ways, and the introduction of cables and wires into the buildings in the blocks is very much facilitated. In London we had to go to enormous expense in introducing a system of underground distribution which probably would not have been necessary if our cities had been laid out on a similar plan to American cities. The labour-saving devices, of which we have seen such splendid pictures, also make one feel envious, and raise a hope that they will be found to have an economical field in this country. I was especially struck by the usefulness of the trenching machine and the pole-line boring machine. Another point in which American practice seriously differs from ours is in the use of overhead cables. That was a method which, when I was connected with the telephone service, appealed to me very strongly. I always hoped that we might introduce it in many situations in which it has been found useful and economical in America as tiding over the interval between the use of open wires and cables. I was told that there were disadvantages in this country, but it was a question on which I retained an open mind, and I should be very glad indeed to hear to-night from Sir William Noble that the further use of overhead cable may be possible in this country.

Mr. A. O. Gibbon: Comparisons with British Post Office engineering methods have not been made in the paper, and it cannot therefore be regarded as a critical review. It is rather a compendium of American practice and as such is most informative and helpful to British Post Office engineers and allied engineers in the telephone industry. Reference is made in Section IV to the weight of copper conductors in underground cables. It is stated that 10-lb. conductors are used in cables ranging from 25 to 900 pairs, and that $6\frac{1}{2}$-lb. conductors are introduced only in cables of 1 200 pairs. In this country we use cables containing $6\frac{1}{2}$-lb. conductors from 10 pairs to 1 000 pairs. Perhaps the author will explain the reason underlying this difference in practice. Is it one of transmission or one of design found most economical from the American point of view? The provision of large "stubs" at branching points for leading-off purposes is given as being the American standard practice. This is an excellent method, inasmuch as subsequent interference with cable joints is avoided. On the other hand, there is a field for the diminishing or tapering system of cable distribution which is regarded as standard practice in this country. Both systems have their advantages, and are of course dependent upon accurate planning at the outset. There is an apparent slight discrepancy in the paper under this heading, because in Fig. 2, where a cable lay-out is shown, there is a tapering system. It may be that this diagram refers to a scattered area, and that the lay-out is not, from the point of view of the Americans, regarded as a tapering network. There are interesting

comparisons to be made in connection with ducts. In Section V the types of ducts used in the United States are shown. American engineers apparently make extensive use of the vitrified clay type of conduit with butted ends, laid in concrete. It is understood that American engineers regard this method of construction as one providing satisfactory insurance against external injury. Inflated costs must presumably be involved in laying ducts under these conditions. The British standard type of duct is made of salt-glazed earthenware with spigot and socket ends, and the ducts are self-aligning. They are made in single and multiple "ways" and are laid direct in the ground without concrete. They are economical to lay and provide immunity from external injury. Perhaps the author will state whether self-aligning ducts as used in this country are utilized to any extent in the United States. Some lantern slides which have been prepared of underground work recently completed between St. Paul's Cathedral and Ludgate-circus may be of interest. The first represents a nest of 56 conduits of octagonal shape. When a nest of conduits up to 9 in number is required, self-aligning ducts are laid; but where large groups of ducts have to be put down in congested city areas, single ducts of octagonal shape are laid and built up to the required number, following fairly closely the practice standardized in America. The second slide illustrates a special type of manhole which has been constructed at Ludgate-circus; the manhole is about 21 ft. below the surface. The author mentions that manholes 40 ft. in length are built in America for the accommodation of cables and loading-coil cases. I do not know where we could construct manholes of this type in the City of London; possibly there is not the same number of obstructions to overcome and there may be greater uniformity in the laying of mains for public services in America. The next slide indicates a somewhat interesting case of congestion at Ludgate-circus. The ducts are lying on the culvert containing the old Fleet River. The roof of the culvert has been specially reinforced with boiler plates. The distance between the top of the culvert and a 48-inch water main is only 15 inches, and 36 ducts were laid in 3 tiers of 12 between the culvert and the main. The pipes in the foreground are pneumatic tubes. In conclusion I should like to state that such visits as the author has made to America are of great value to engineers generally; we are enabled by means of his review to obtain a better knowledge of standard methods in telephone engineering in America and to profit thereby. In the Post Office Engineering Department it is our privilege to receive many visitors from colonial and foreign administrations. I respectfully suggest that return visits from Post Office engineers might be made.

Mr. J. M. Shackleton: I hope the author in his reply will amplify the tree given on page 86 and give some information about the organization under "Division Engineers." Can he tell us who corresponds in the A.T. & T. Co.'s staff to the Controller, Stores Department, in the Post Office? Presumably the "Commercial Engineer" shown on the right-hand side of the tree concerns himself only with the development studies, and in this connection it should not be overlooked that such studies are at best but intelligent guesses; in London, particularly in the older portions where ancient houses are being replaced or may be replaced by new office buildings, it is extremely difficult for the Contract Department to predict exactly what is going to happen even 2 years hence, much less 10 or 20 years hence. The author mentions that, as a general rule, when existing cable is filled to the extent of 60 or 65 per cent, new cabling is commenced; that roughly corresponds to our experience here. In other words, the cable efficiency in New York will be somewhere about 50 per cent. I should like this figure confirmed. The author mentions that in America earth wires are not used on poles. It is only recently that the Post Office ceased to earth wire arms on telephone lines and I think we might go further and discard pole earths in many cases, if not altogether. On page 91 the author states that 165-lb. or 96-lb. copper wire is used for subscribers' lines; for long-line service I can understand the use of such heavy wire, but I should like to know why it is necessary to use a wire heavier than, say, 40 to 60 lb. on subscribers' lines. With regard to the cable terminals referred to on page 96, we have experimented with some American types in England but the climate has been too onerous for them and we now use an all-lead-covered termination, which stands the climate but lacks flexibility, and experiments are still being carried out with a view to finding something better. As the author is familiar with the U troughing in use by the Post Office perhaps he can tell us whether such troughing is ever used by the A.T. & T. Co. With regard to heavy conduit lines, I take it that in the case of, say, 100 ducts the A.T. & T. Co. would build up from sets of 6-way or 9-way ducts. Such a method would not be suitable in the centre of London; a single-duct "monobloc" is much more flexible, as the formation can be altered if obstructions are met with. I should be interested to hear what the A.T. & T. Co.'s experience is with silk and cotton-covered cable. Our difficulty has been to obtain a suitable leading-in cable that does not take up too much room, that will maintain its insulation and is not unduly costly. The use of stub joints is interesting and I think we might with advantage use them to a much greater extent than is now done. I gather that in the United States, certainly in New York, there is nothing corresponding to the cable-distribution head as used in this country. As regards routing and cross-connection work generally, can the author say how in New York they take care of miscellaneous circuits, e.g. private wires, exchange extensions, etc.? If such circuits are not routed via exchanges the cable system becomes complicated. The house cable system described in the paper is similar to English practice except that in central London, owing to the fact that it is so very difficult to estimate subscribers' development, it has been found necessary in certain cases to terminate both the street cables and the branch cables on a main frame, thus giving the maximum amount of flexibility. Finally, I should like to ask the author if he can give the average time it now takes in New York to connect a new subscriber to the system, that is to say, what length of time elapses between the

applicant signing the agreement and getting the telephone installed. Similar information for the pre-war period would also be of interest.

Mr. F. Gill: Sir Andrew Ogilvie has said that glass insulators are no good, but I am not sure that I agree with him. There has been a great advance in the past few years in America in regard to such insulators. At the present moment they are used all over the United States and Canada, also in other parts of the world. In certain parts of the United States there are climates which are just as injurious to insulation as any in this country, and I am of opinion that the glass-insulator problem is worth studying. The American Army brought glass insulators over to France during the war; they worked very well then and I believe they are still working well. The author has given some of the requisites for aerial cable, one of which is the sheath. It is very important that aerial cable should have a correct sheath, and that is not a pure lead one.

Major H. Brown: The author is apparently an advocate of the system of waxing joints. I will therefore mention briefly the arguments for the other side. The practice of many of the firms that carry out cabling work for the Post Office is not to boil out the joints with wax. They contend that they can meet the Post Office requirements as regards insulation resistance without the use of wax and that the cost of doing so is not greater than if wax were used. It is also claimed that there is difficulty in identifying the colours of the various pairs of conductors when wax has been used, thereby rendering it easier for wrong connections to be made. Further, the wax on the paper insulation is likely to cause faults, owing to the tendency of the paper to crack if it is handled after being treated. In view of these objections the Post Office in its contract work has not insisted on the method being followed. So long as the electrical condition of the cable when handed over complies with the Specification, the Post Office is satisfied. The Post Office has, however, laid down that, so far as the jointing work which is done by its own staff is concerned, the boiling-out process is to be regarded as standard practice. This does not mean that it is invariably done, but that wherever the process is practicable it should be followed. The Post Office staff has also met with the objections to the method experienced by some of the contractors, but on the whole it is considered that the majority are in favour of the waxing process. In regard to the solid filling of joints, when a Post Office delegation came back from America recently it was stated that the American practice was not to test the plumbers' work and sheathing of cables with air pressure because it was found that the best test was to fill the joints solid with wax. They were told that if wax at a temperature not less than 350° F. was poured into a joint, it would run through any faults in the plumbing and could readily be detected on the surface of the lead. In order to test the matter a very faulty wiped joint was made. It was proved to be faulty before it was filled with wax, but after wax had been poured in we were quite unable to detect any leakage through the faults. As the joint was much more faulty than is likely to be met with in actual practice it was felt that there would be a danger of masking bad work if the process were adopted. The Post Office has found pressure-testing to be a satisfactory method for proving plumbers' work. The usual practice is to pump dry air into the cable until a pressure of 20 lb. per square inch is registered, and then to smear the joints with soap suds. In the event of a joint not being perfect the escaping air blows a bubble at the fault. This test is a sensitive one, and by its means it is possible to detect faulty joints in which the metal is merely coarse due to a deficiency of tin. The continuity of the sheathing is tested by applying air pressure to the cable until a sensitive gauge at each end registers a pressure of 20 lb. per square inch, and by allowing the cable to remain under pressure for 24 hours. If at the end of the time there is no observable loss the sheathing is taken to be satisfactory.

Mr. A. Moir: Do the Americans in their congested streets adopt subways at all for cabling purposes? In Paris, the cables are carried along the sewer subways, which are quite high. The sewer runs at the bottom of the subway; and along the walls there is an arrangement for racking up the cables on both sides, and I have never seen a better system for providing a run for cables. In the newer streets in London, subways have been provided which accommodate the cables or pipes for the telephone service, gas, electric light and all other undertakings, but in the older streets nothing of the kind has hitherto been provided. The slides shown by Mr. Gibbon gave some idea of the obstructions that arise and of the very heavy cost of laying down additional ducts or pipes, but in some of the City streets the obstructions are very much greater. If a subway capable of accommodating the cables and other paraphernalia of all the undertakers who use the streets were laid down, as the roadway comes to be renewed along Oxford-street, let us say, it would afford all the facilities for putting these conveniences down in a proper manner. Future works would have to go into the subway, and in that way much of the traffic obstruction which takes place in our streets would be avoided. Have the Americans done anything of that kind in their more congested streets?

Sir William Noble: One or two speakers have remarked that we have a good many foreign visitors to this country who come to learn something of telegraphs and telephones, but that very few of our engineers go to other countries to learn what is happening there. I should like to say that it is not necessary to send more than we do at present. I should like to know whether the company with which the author is connected will adopt the labour-saving devices that he has referred to, and persuade the other companies which work for the Post Office to do the same. The author states that normally 100 pairs of wires are jointed per hour, but that as many as 300 wires can be jointed per hour, that is, 5 joints per minute. I hope the author will take some part in producing that result in this country. He also tells us that 8 men erect 300 poles in 8 hours. At the present time we in the Post Office do not employ contractors to erect poles, but if the company with which the author is connected, or any other company, will undertake to erect 300 poles with 8 men in 8 hours

we will hand over the work to them. The author also says that the Americans draw in large cables at the rate of 50 ft. per minute, that is, almost 1 ft. per second. I hope that also will be done by the contractors who are working for the Post Office. Up to the present time we have not seen such a working speed. I had no idea until I went to America that they adopted aerial cables to such an extent as they do. On my return I asked my officers to investigate the matter, and we proved conclusively that in this country our practice is efficient and economical, that is, for a small number of circuits to use light poles and light wires, and not, as is apparently done in the outlying parts of America, to use iron wires or aerial cables. We use 40-lb. bronze wire, and this light wire and these light poles are more economical than aerial cables for a small number of circuits. Then in America they have this advantage, that it is possible to travel many miles along a road without meeting trees and other obstructions. It is impossible to go far in this country without running against trees and going through villages. After every storm a large number of wires are brought down by the trees. If a main cable is brought down in a few places by trees, much more is involved in replacement than in stringing up aerial wires. Furthermore, with the conditions that obtain in this country, of so many towns and villages having to be passed through, we find that it is far more economical to lay wires underground, and it is certainly better practice. The author refers to the labour-saving devices used in America. This, however, is not a matter that we have neglected in this country. We gave it a great deal of consideration, but it must be remembered that this country is much smaller than America. In America there are great stretches of country and wide margins on the roads which lend themselves much better to the use of labour-saving devices than is the case in England. It might be mentioned, however, that a prominent engineer in America, reporting to his chief about one of the trenching machines, said: "Its operation is uncertain and often unsatisfactory and can hardly be said to have 'proved in.' The machine was out of service for repairs, delays due to weather, moving, etc., approximately 50 per cent of its time." I think there is a great deal of truth in that. We asked some contractors who do the underground work for us to give such a machine a trial. One of them did so, but he gave it up, for apparently the same reasons as the engineer whom I have quoted—that a gang of labourers could do the work more cheaply than the machine. How could we in our congested roads, to say nothing of the trees and villages, employ excavating machines for trenching work, back-fillers, tamping machines, concrete mixers, pole-hole excavators, pole erectors, and air-driven drilling machines? It would be quite impossible in this country to use even one or two of these machines, for want of road space alone. America believes in labour-saving devices and it often pays to use them, because the cost of labour is higher there than it is here—it certainly is very much higher than it was before the war—and that probably is one reason why they adopt these labour-saving devices to such an extent. It may be that, in view of the higher wages now obtaining, it would pay us now to use some of these appliances where we did not do so before, but that is a matter for investigation. The Post Office, however, does not neglect motor vehicles, and has now over 700 of different kinds in use.

Mr. J. E. Kingsbury: In his remarks with regard to the statement that the A.T. & T. Co. are said to control 12 600 000 telephone stations, I apprehend that Sir Andrew Ogilvie has given a somewhat wider meaning to the word "control" than the author has intended. It is obvious that one telephone organization may have most efficient lines, and yet, by connecting up with some other organization with very inefficient lines, a disastrous result will be produced. Now, it is one of the governing principles of the A.T. & T. Co. that they will not connect up with any other company's lines unless there is a certain standard of transmission, a certain type of instrument, and lines of a suitable quality. I expect that Sir Andrew contemplated a general financial and other control which, as he says, they do not possess, but that the author contemplated an engineering control, which in fact they do possess. I regard this paper as one which will be studied by a much wider audience than is now present, and I am therefore of the opinion that the question of engineering control over connecting lines should be brought out in the discussion. Such a condition as that which the A.T. & T. Co. imposes is one that should be borne in mind in any cases where intercommunication is afforded by a telephone authority to independent organizations in outlying areas.

Mr. S. C. Bartholomew (*communicated*): I should like to have further information on one or two matters in which I am more particularly interested at the moment. First of all, however, attention should be drawn to a statement which may mislead engineers in this country unless it is amplified. This statement occurs at the bottom of page 91. "The joint use of poles for telephone and electric supply wires is greatly encouraged. The advantages are mutual, particularly on small routes for distribution purposes." I made inquiries some few years ago of an eminent American telephone engineer as to why the joint pole construction is followed, and the explanation he gave was to this effect. The American telephone authorities would naturally prefer to keep the overhead telephone plant as far as possible from the electric supply wires and would do so if they had powers similar to those of the Postmaster-General in this country. In the absence of these powers, or of an authority with functions corresponding to those of the Board of Trade (now the Electricity Commissioners), most unsatisfactory conditions arose with the growth of the industries, the electric light and power wires being run without much regard to safety of telephone plant, and, in the absence of control, mutual arrangements had to be made to do the best possible in the circumstances. The use of joint pole construction resulted, and I was told: "Before joint pole construction was introduced the power wires had no definite position; but now we know where they are and, further, that the wires will be put up with a certain factor of safety embodied

in a Specification. The arrangement has been very beneficial, as the average number of our (telephone) linemen killed per year has been reduced from 49 to 6." If we set against that casualty list the fact that in this country there have been only 3 cases of Post Office linemen being killed owing to electric shock in a period of, say, 50 years, it is obvious that the conditions in this country as regards safety of telephone linemen is infinitely better than in the United States, making every allowance for the great difference in the amount of overhead plant. As regards the 3 men killed in this country, it should be noted that two of the accidents occurred at joint poles, i.e. at poles where extra-high-pressure overhead wires and telephone wires cross at a common structure, and in the remaining case guard-wires had not been provided by the power company at a crossing, and the Post Office lineman received a shock from a circuit having a pressure of about 250 volts to earth. This question apparently affects also the telephone subscribers in America. An American "Safety First" Society publishes a series of warning pictures illustrating, among other things, the untimely end of a subscriber who on observing flashes of fire at his telephone instrument proceeded to cut the wires with an ordinary pair of pliers. This lurid warning must have had a basis in fact to have received this prominence, and it need hardly be said that the death of a subscriber in this country by such a means would have far-reaching consequences. I think it must be recognized that in this and other matters affecting the mutual interest of telephone and power supply authorities the conditions in America differ materially from those obtaining in this country, and the fact that the joint use of poles for telephone and electric supply wires "is greatly encouraged" is due to circumstances which do not exist here, and it is a fair assumption that such construction would not be encouraged by American telephone engineers if they were working under the same conditions as obtained here. There are several references in the paper to the corrosion of lead-covered cables by chemical and electrolytic action, and it would be of great value if a comprehensive statement could be made as to the experience in the United States and the methods adopted to combat these subtle foes. It is implied on page 89 that alloys of lead and tin, and lead and antimony, resist chemical action. What is the basis for this assumption? It does not appear to be borne out by the experiments carried out by the American Bureau of Standards and referred to in their pamphlet No. 377 of 6th August, 1920, on the "Intercrystalline brittleness of lead," as the tests seemed to point to the fact that the alloys are more subject to disintegration than the pure metal. Reference is made on page 96 to an insulating joint in lead-covered aerial cables to prevent the flow of current in the underground section. I am not clear whether this is to prevent stray currents picked up by the sheathing in the underground section from flowing into the aerial cable sheathing, or the reverse. Or is it the practice to use insulating joints in the underground sections at selected points to prevent electrolytic action? On page 97 under (9) of the advantages obtained by using aerial cable, it is claimed there is practically no risk of electrolysis; this, I think, is a very real gain. Electrolytic action on the lead covering of cables placed underground is very difficult to guard against with certainty, and it is a costly business nowadays to replace a section of cable where balanced and loaded conductors are concerned. On page 100 it is stated that American engineers consider that no kind of lubricant forms an effective preservative against chemical or electrolytic action on the lead sheath. It is the practice in this country to cover the cable liberally with petroleum jelly during drawing-in, the amount being in excess of that actually required as a lubricant. Petroleum jelly is an inert material and, if the sheathing is effectively covered, it should prevent chemical action in those rare cases where harmful matter deleterious to lead is present in the ducts. It is obvious that some of the jelly will be removed during drawing-in, and in that sense it cannot be "effective" at all points, but as the greater part remains it must to that extent be a safeguard provided at very little cost. It is open to question whether it provides against electrolytic action, and I do not think that claim has been made here. Under the head of "Bonding" on page 103 reference is made to earthing of the lead sheathing at manholes as not being reliable. What exactly is meant by this? It is not advisable to earth-connect if the earth is positive, but very desirable where the cable sheathing is positive. Is it because the conditions in this respect may for some reason be reversed that it is considered best to avoid direct earth connections altogether? It would be of considerable interest if particulars could be given of the periodical tests of leakage current made between the cable sheathing and earth referred to in the same paragraph, and of the remedial steps taken when certain limits are exceeded. It is the practice here to measure the currents in the sheathing and deduce what current is going to earth from the difference in the readings at adjacent manholes. A test between sheathing and earth will not give a true indication of the current leaving the sheathing; it is simply a voltage reading. It is possible to have a big difference of potential between cable sheathing and earth and yet have a very small current in the sheathing. The conditions in America as regards electrolytic action by stray currents differ considerably from those obtaining here, the stray currents being of greater magnitude, and the experience gained there is very valuable, as ideas and methods can be tried out and their effectiveness or otherwise soon proved. I also should like to take this opportunity of putting on record my appreciation of the way in which American telephone engineers have freely given the results of their experiences in this and other matters.

Captain H. Carter (*communicated*): Since the author does not compare the merits of British and American practice, I propose merely to ask for further information on a few points which he has raised. On page 90, it is stated that the A.T. & T. Co. do not consider it necessary to provide earth wires as a protection against lightning. I understand that it was once their practice to fit an earth wire to every tenth pole of a toll line. Has this practice been discontinued? Is the author in a position to say whether any considerable amount of damage is done to the poles by

lightning? It is well known that American telephone administrations are prepared to take more risks than would be admitted in this country, as is evidenced by the number of linemen who receive injuries each year from power lines. Perhaps they are prepared to take similar risks as regards lightning. In Fig. 5 two bridle wires are shown passing through the electrose insulator, but both are connected to the same line wire. Can the author say why this is done? In Fig. 11 a rope mat is illustrated as a protection to the sheath of the cable whilst it is being pulled round an angle against the pole. Is any permanent protection provided for the cable in such a case after erection? It would seem to be a dangerous procedure to leave a cable in contact with a pole, but I have been unable to find reference to any form of permanent protection in the A.T. & T. Co.'s instructions. On pages 95 and 97, the author refers to ring cuts in cable sheathing. Will he state if he uses the term to indicate cuts in the sheathing due to pulling in, or to damage sustained after erection by wind vibration? It seems almost inconceivable that a cable can be supported in a ring so much larger than itself without some relative motion occurring between the two, which motion must have a wearing effect on the sheathing. Marline ties near the poles would appear to have little effect towards preventing ring cuts of this nature over a greater part of the span. I shall be very interested to hear whether such a difficulty has been met with and, if so, how it has been overcome. I understand that the A.T. & T. Co. are taking out a patent for an anti-vibration device for aerial cable rings. Does not this indicate that trouble has been experienced? On page 97, col. 2, the factor of safety for aerial cable pole lines is quoted with an ice coating and a 70-lb. wind pressure. I would point out that a wind pressure of 70 lb. per square foot corresponds to a wind velocity of about 150 miles per hour, which, even in America, seems a little excessive. I frequently refer to an American book on line construction which does not classify winds beyond 100 m.p.h., and even this velocity it alludes to as an "immense hurricane." In addition, we know that the basis of American calculations of wind pressure on ice-coated wires is usually 8 lb. per square foot. Is there not some error in the statement contained in this paragraph? The performance of erecting 40 poles per hour with the aid of a pole-erector alluded to on page 109 is surprising. It would appear that after moving the erector from one pole to the next, manœuvring it into position suitable for use, and adjusting the sling chains to the pole, there would not be much left of the $1\frac{1}{2}$ minutes stated to be taken for the erection of each pole. Regarding the question of glass versus porcelain insulators, raised by Sir Andrew Ogilvie and Mr. Gill, my limited experience of glass insulators in wet weather leads me to support the latter's contention that there is not much difference between the performance of the two materials. Porcelain insulators as at present made are, however, very satisfactory and, before a change in practice in this country could be justified, it is necessary either that glass insulators be proved to be very superior to porcelain insulators and to be obtainable at approximately the same price, or that they should be proved to be equally good and considerably cheaper. No glass insulator has yet been put forward which can fulfil either of these conditions, and at present they cannot be manufactured in this country.

Mr. H. Green (*communicated*): On page 93 it is stated that 10-lb. cable is supplied in two types, one for aerial use and the other for underground. I was not aware of this previous to the author's visit to the United States, and I do not think he makes it quite clear why the dielectric strength of aerial cable should be greater than that of underground cable. I understand that he intends to mean that the thickness and strength of the paper (dielectric) is greater in the former case, or, in other words, with the use of thinner paper insulation on underground cables an economy of duct space is obtained. On page 94 the author mentions the universal method of securing (or testing the existing) tension in the suspension strand. This method was frequently employed by open-wire construction companies in the field in France. An article * on this was written by Captain Timms, of the Post Office. The method of providing an aerial conduit by means of steel cable rings (see page 94) was tried and proved successful by the National Telephone Company before 1911, and no doubt would have become their standard practice for the suspension of aerial cable. Obviously the art of rapid underground cable-placing has been brought, in America, to a very high standard, and to some the work done may appear incredible, but in my opinion the same amount of work could be accomplished in this country, providing the conditions were equal. It is precisely what was experienced in the Army with intensive training of unskilled men on overhead line construction. The results of team work to a definite drilling schedule were astounding to experienced engineers, when compared with the speeds with which work was usually carried out in civil practice. No doubt, again, the speeds mentioned under the heading of "Cable Jointing," appear incredible in view of the very different results obtained in present-day practice, and I must say I am one of those who consider that British jointers are quite as capable of performing these speeds as those in the United States if only they were properly trained and wished to do the work as quickly. Nowadays, the speed of jointing in this country leaves much to be desired and, to my mind, compares unfavourably with old practice. I have records taken personally in 1906, of jointing speeds on various sizes of cable and conductors, and they show that it was quite a normal performance for a first-class jointer to joint 60 to 75 pairs per hour, i.e. wiring and soldering on $12\frac{1}{2}$- and 10-lb. conductors. Quite apart from these records I can recollect in 1903–4 jointers regularly jointing completely 312/20 cable in a normal working day of 9 to 10 hours, and in 1906 it was considered quite normal for a jointer to make a 600/10 joint in a day of 12 hours, but in these cases, owing to a purely local arrangement, the plumbing work was not carried out by the jointer, but by a plumber.

Captain J. G. Hines (*communicated*): The references in the paper to the method of carrying out a develop-

* *Journal of the Institution of Post Office Electrical Engineers*, 1920, vol. 12, p. 221.

ment study, the preparation of a fundamental plan, the design and lay-out of plant, and the wiring of large buildings, might serve as a description of British standard practice. Although London does not possess so many mammoth buildings as New York and some other American cities, there are many large buildings in which the telephone density approaches or surpasses that quoted by the author on page 105. For example, within a few hundred yards of London-wall exchange there is one building of 700 000 sq. ft. floor space which is served by two 800-pair cables and has three risers of 600 pairs each, one of 500 pairs and one of 300 pairs. Another adjacent building of 62 000 sq. ft. is served by 1 250 external lines, i.e. one line per 50 sq. ft. Yet another of 46 000 sq. ft. is served by 800 pairs, i.e. one line per 57 sq. ft. The American building quoted by the author has one external line per 300 sq. ft. There are probably buildings in America in which the telephone density is greater. The comparison is made simply to show that the problems are similar and are solved in a similar way. There are three important differences, viz. (1) The extent to which mechanical aids are used; (2) the extensive use of suspended cable; and (3) the speed of working. Items (1) and (2) are largely accounted for by the differences in the character of the roads, the nature of the climate, and the attitude of the public towards telephone supports. I wish the grantors of wayleaves in this country could be persuaded that "plant of this type is neat and inconspicuous and does not raise any objections on æsthetic grounds." I hesitate to estimate how much time is spent by British telephone engineers in trying to convince people that the much neater type of open line used in Britain as compared with that in America will not depreciate the property on the route. On page 100 it is stated that 20 men drew in 4 miles of cable in 10 hours. As on page 109 it is stated that the average speed of drawing-in is about 50 ft. per minute, the cable would be actually moving along the duct for 7 hours. This leaves 3 hours during which the cable tackle had to be moved forward 22 times, i.e. 9 minutes were available for the operation of disconnecting the gear, moving it forward 300 yards and connecting it up again. This would be very smart work, even in America. If additional winches were used, the number of men available for the essential auxiliary operations of unlagging the drums, fixing cable grips, preparing and sealing ends, etc., would be reduced. The quickest work I have been able to trace as having been done by a British contractor in one day is 1 643 yards by a gang of 29 men. As contractors work for profit and are not restricted in the use of mechanical haulage or the organization of their work, it is difficult to understand why they should be so hopelessly outclassed by American firms. Can the author throw any light upon this point? I should be glad if he would say in his reply what stress was applied to the cable in order to produce a speed of 50 ft. a minute, and also what was the clearance in the duct. I have carried out some tests to determine the stress applied to cables of 2·9 inches diameter when drawn into $3\frac{1}{4}$ inch ducts 150 yards long. At the end of the pull the stress reached 1·45 tons. The mean speed was approximately 15 ft. per minute. I am very doubtful if a cable would stand the strain of being pulled in at a speed of 50 ft. per minute unless much greater clearance were given. Greater clearance, however, involves less space being available for wires, and it is much more difficult to get space in the congested streets of English cities than in the newer cities of America.

Mr. G. A. Hollings (*communicated*): The author's figures with regard to the rate at which work is done in America will amaze engineers in this and other countries. Different countries offer their own peculiar problems for engineers to unravel. Some years ago I was confronted with static trouble of a particularly elusive nature in the Deccan. The line was a 70-mile metallic telephone circuit, worked on the "omnibus" principle. It was the sole circuit on an excellent iron-pole route that had been built for the purpose along a railway, but which was well away from companion routes. The shortest distance from the route to the nearest electric supply plant was 100 miles. At times on the finest days the circuit was rendered unworkable, owing to the fact that powerful shocks of a continuous nature were experienced on every attempt to touch the hand microphone cords. On other days when the trouble was less pronounced, deafening reports would occur in the receivers. The fitting of earth drainage coils allayed the trouble, but these coils were themselves unable to withstand the strain. The trouble became aggravated during the monsoons and eventually the installation of numerous spark-gaps was undertaken, with the result that the trouble was reduced to a negligible quantity. We referred the matter to authorities in this country, but without any useful result. Perhaps the author would say if he has heard of similar trouble in America and whether any steps other than those of the well-known kind have been adopted there to counteract it. The telephone authorities in this country apparently do not consider it necessary to countenance instruction visits to the Colonies and India. They have thereby unknowingly debarred themselves from a large field of study. Many of the old controversies regarding plant which have been allowed to lapse here owing to the fact that a definite solution was never forthcoming and never pressing, have had to be solved by engineers in places where the exigencies of the climate demanded it. In some countries where the destructive processes of nature are extremely searching and rapid in their effects on telephone plant, much invaluable information may be gleaned from the engineers who have had to devise special methods, and whose problems in numerous cases are reproductions of difficulties encountered in this country but in an intensive form. Unfortunately, the vast experience of these officials is rarely probed by their confrères here, who are probably unaware that there is so much they could learn regarding telephone practice from visits to various parts of the Empire.

Mr. H. G. S. Peck (*communicated*): I should like to ask the author for further information on the following points: (1) In the paper it is stated that the fundamental plant lay-out is revised every 5 years. Is the development forecast revised continuously during

each period of 5 years, or is an attempt made to revise it as a whole every fifth year? (2) Are any limits set with regard to the provision of external exchange extensions, and by what routes are such circuits provided, that is to say, are they taken into the main exchanges on the distribution cables, or is some linking-up scheme of cables provided between the different exchange areas or parts thereof? (3) What is the usual busbar voltage at the main exchange, and the general method of distribution to both large and small private branch exchanges? (4) What is the method of providing the main frame accommodation for the cables required for three or four 10 000-line units in one building? Is an attempt made to connect all the cables to one large main frame, or are they divided in any manner between different frames? (5) Is any considerable use made of local battery instruments in order to provide a requisite transmission over long exchange lines or external extensions?

Mr. E. S. Byng (*in reply, communicated*): I greatly appreciate the cordial reception of my paper and thank the various speakers for having raised so many interesting and practical points, particularly in regard to telephone practice in this country.

Sir Andrew Ogilvie rightly draws attention to the difference between "associated companies" and "connecting companies," and his remarks, read in conjunction with Mr. Kingsbury's definition of what should be understood by the term "control," will make the relationships of the telephone companies quite clear. I am glad Sir Andrew has laid stress upon the large number of experts engaged solely on Engineering Development work, as it indicates the thorough manner in which all matters relating to engineering practice are studied before being adopted as standard in the Bell system. The definition of the term "engineer" is perhaps not quite broad enough to cover all that is implied in this connection. The men employed on the design and lay-out of plant and the preparation of specifications for construction works are also called engineers, although they are not engaged on "abstract study." The line of demarcation is drawn between such men and executives actually in charge of construction and maintenance works—these being known as superintendents and supervisors. Sir Andrew makes a strong case against the use of glass insulators in this country, but, as Mr. Gill points out, there may be a field for them in some parts of Europe if they prove efficient and economical. The exceptional humidity of the British climate is referred to by Sir Andrew in this connection and again when dealing with open-wire loading and desiccators. While it is true that the climate in the Central and Western States is very much drier than in this country, in the Eastern States (known as the Atlantic seaboard) the atmospheric conditions have practically the same effect upon telephone plant as is experienced in Great Britain. On account of these conditions iron wire has a very short life, and copper wire for overhead conductors proves much more economical.

Mr. Gibbon raises the question of $6\frac{1}{2}$-lb. copper wire in cables; his deduction that this size of conductor is used solely for the 1 200-pair cable is substantially correct. I believe that consideration is now being given to the economy of using this size of wire in small distribution cables where the transmission limits will not be exceeded. The apparent discrepancy between the reference to feeder cables in the text and the lay-out shown in Fig. 2 is explained by the fact that tapering cable is usually adopted only on the outskirts of a district (as shown in the figure) where there is but little possibility of the boundary being moved. A diminishing cable brings results in an economy of cable, but American engineers consider such initial saving to be frequently offset by the increased cost of providing relief. In consequence, feeder cables usually do not taper but have a large stub cable teed in at every manhole where distribution is required. Mr. Gibbon asks if self-aligning ducts are used to any extent. Mention is made in the paper of trials at present being made with a similar type of duct which is expected to prove advantageous on some routes. In general, however, a duct route is not less than a 4-way, except in the case of single-way laterals. The increase in cost due to the use of concrete is not so serious as might be imagined. The route usually follows the roadway rather than the footway; therefore the additional cost for concrete only is small in relation to the total cost.

Turning to the chief points raised by Mr. Shackleton, the character of the organization under the Division Plant Superintendent depends, as already mentioned, greatly upon the size and nature of the territory controlled. Nevertheless, the staff tree shown in Fig. A indicates in a general way the type of organization which would probably be followed in a fairly congested territory. There is no Controller of Stores as generally understood in this country. The Western Electric Company, in addition to manufacturing or purchasing the materials and tools required by the associated companies, holds in its various distributing houses a stock of the plant necessary for the construction and maintenance staffs. This arrangement makes it unnecessary for the associated companies to carry large stocks. It will be observed that a "Supervisor of Supplies" is shown in Fig. 1; this officer co-operates with the Western Electric Company's distributing house. A hard-and-fast rule cannot be given for cable efficiency, as in a dormant territory cables may be worked to a "fill" of 90 per cent or more before relief is provided. The object, however, is the same as in this country—to avoid too great a proportion of idle plant. At the same time it is preferred to keep the proportion on the high side rather than the reverse. This policy tends to stimulate the demand for service. Mr. Shackleton inquires why 40- to 60-lb. wire is not used for subscribers' lines. Copper wire of these gauges has not the requisite tensile strength; bronze wire would therefore be necessary. In Great Britain the primary reason for using bronze was the need of combining strength and lightness in the wire attached to house-top fixtures. Possibly this reason did not hold in America; and with the increasing use of cable for distribution, and the adoption of covered drop wire for termination at subscribers' premises, the scope for bronze wire under American conditions is likely to become still narrower. For long open-line routes

102-lb. copper wire is used if iron wire has not the requisite life; the heavier type of copper being used only for long subscribers' circuits requiring a high grade of transmission. U troughing is not adopted except in reconstruction or repair work where a single- or multiple-way split-tile duct is sometimes laid. This consists of two parts placed together to form a circular duct, which is then surrounded by concrete. Apart from this special case all types of duct are laid in advance of the cable. For heavy conduit lines a nest of multiple-way ducts would be used wherever a fairly clear run could be obtained. Failing this, single-way tile ducts similar to the type described by Mr. Gibbon are laid in concrete, unless the obstructions are too serious, in which case steel pipes set to the shape required would be used. So far as I am aware, no trouble arises from the use of silk- and cotton-insulated lead-covered cable for leading-in at central offices. As soon as the cable is opened for "forming" it is boiled-out in hot beeswax, beginning at the sheath and working towards the end of the exposed wires. When the "form" has been made, but before it is placed in position, it is given a light coat of shellac. This operation is repeated after erection on the frame. If dampness is feared, the cable form is further coated with a black insulating paint, known as "P.B." paint. Cable distribution heads are not used, all connections being made either in the joints and covered by lead sleeves, or at the ends of the cable stubs. Miscellaneous circuits are usually routed via the nearest exchange for cross-connection. Possibly in an outlying district, rather than monopolize two circuits in the main cables, advantage would be taken of the party-line facilities, and connection would be established via the cable stubs. The average time for supplying telephone service is normally about one week, but since the war an unprecedented demand, which has resulted in serious shortage of plant in some districts, has occurred in New York. For instance, in one month alone in 1921 the New York Telephone Company connected 17 000 new stations. In view of the size of the organization I was impressed by the small amount of routine between the signing of the order by the subscriber and the receipt of a works' order by the official responsible for handing the work out to the installation men. Thanks to the liberal provision of cable terminals in each system of distribution, service is readily established under normal conditions. Sometimes the subscriber has to wait only one day. A month's subscription is paid in advance when the order is signed, so that connection is not delayed upon completion of the installation work.

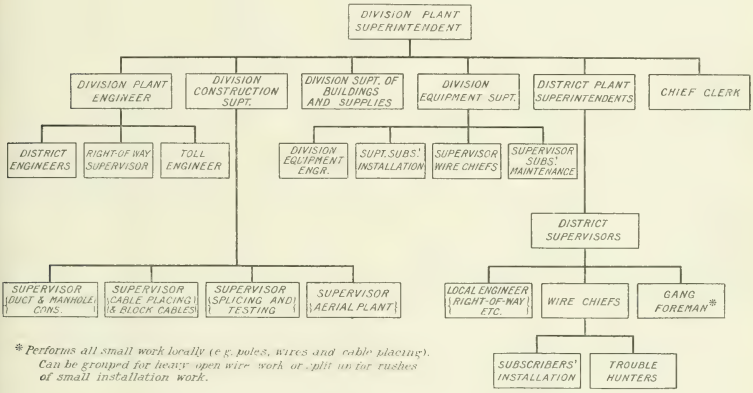
DIVISION PLANT SUPERINTENDENT
DIVISION PLANT ENGINEER
DIVISION CONSTRUCTION SUPT.
DIVISION SUPT. OF BUILDINGS AND SUPPLIES
DIVISION EQUIPMENT SUPT.
DISTRICT PLANT SUPERINTENDENTS
CHIEF CLERK
DISTRICT ENGINEERS
RIGHT-OF WAY SUPERVISOR
TOLL ENGINEER
DIVISION EQUIPMENT ENGR.
SUPT. SUBS' INSTALLATION
SUPERVISOR WIRE CHIEFS
SUPERVISOR SUBS' MAINTENANCE
DISTRICT SUPERVISORS
SUPERVISOR (DUCT & MANHOLE CONS.)
SUPERVISOR (CABLE PLACING & BLOCK CABLES)
SUPERVISOR (SPLICING AND TESTING)
SUPERVISOR (AERIAL PLANT)
LOCAL ENGINEER (RIGHT-OF-WAY ETC.)
WIRE CHIEFS
GANG FOREMAN*
SUBSCRIBERS' INSTALLATION
TROUBLE HUNTERS
* Performs all small work locally (e.g. poles, wires and cable placing). Can be grouped for heavy open wire work or split up for rushes of small installation work.

FIG. A.—Bell Telephone System: typical staff organization controlled by Division Plant Superintendent.

The remarks by Major Brown regarding the "boiling-out" of joints are of considerable interest to telephone engineers, especially as the difficulties sometimes encountered in this country do not appear to be experienced in America. The temperature of the wax and the quality of the paper insulation may have some distinctive bearing upon the alleged brittleness of the paper and on the obscuring of the colours. The design of the cables in the two countries is also somewhat different, and this may contribute to the objection to the use of wax in this country. All American engineers with whom I came in contact strongly advocated the "boiling-out" of joints, particularly when the manholes are in damp locations. Major Brown refers to the filling of joints with wax in order to prove whether the plumbing is good. Although this point is not mentioned in the

paper, inquiry was made as to the efficacy of the wax test. If properly applied and observed, the engineers considered that any defects in plumbing work should be detected. Reliance is placed upon the quality of the plumber-jointers' work, and breakdowns due to defective plumbing are so rare that it is not therefore considered economical to apply an internal air pressure test. Only the **Y** joints are filled with wax and, as explained in the paper, the primary object is to retard the entrance of moisture should the joint at any time break down.

In reply to Mr. Moir, I am not aware that subways have been provided in any of the large cities in the Eastern States. In Chicago there are some 60 miles of tunnel constructed under the most important streets of the city. These tunnels are $7\frac{1}{2}$ ft. high $\times$ 6 ft. wide, and are entirely lined with concrete. The franchise obtained by the Telephone Company for an automatic telephone system provided for the construction of tunnels to carry an all-cable system of distribution. These tunnels were completed about 1908 at a cost of approximately £11 000 000. In addition to the original function of carrying telephone cables, the tunnels are also used for the conveyance of freight by small electric trains. It should be mentioned that American engineers use the word "subway" to indicate a duct system together with the associated manholes; consequently the term may be a little confusing to engineers in this country.

Sir William Noble's doubts regarding the speed of construction work in America are probably due to the fact that I did not make it sufficiently clear that the figures given for completed work represent the *maximum* record reached under *the most favourable conditions*, and can therefore be used only as a high-water mark. From that point of view they are useful. Between the various sections of an associated company, and between one company and another, there is a keen friendly rivalry which fosters the desire for record-making, especially when conditions are favourable. The average speeds of work would probably not exceed 50 to 60 per cent of the maximum in the case of cable installation. For example, the rate for drawing-in cable mentioned, viz. 50 ft. per minute, is quite a normal figure, and I verified that this was often exceeded under varied conditions in three different parts of the country. The maximum average speed allowed for pulling cable into an underground conduit is 90 ft. per minute. I was not present on the occasion when 4 miles of cable were installed in one day, but the information regarding this feat was obtained from several entirely different sources, including the engineer-in-charge, and I am therefore quite satisfied that it was authentic. According to my personal observations of aerial cable erection, the progress during one week ranged from 20 to 24 drums per day. This was on a portion of the New York–Chicago aerial cable route, running over the mountain ranges indicated in the lantern slides. Transport on this route was so exceptionally difficult that even without corroboration I should have found no difficulty in accepting the record attained under ideal roadway conditions. Some of the reasons contributing to this fast work are mentioned in the paper, but the main secret lies in efficient organization. Not a word is shouted; each unit, knowing its work thoroughly, goes ahead without loss of energy or time in conversation. The output of cable from the works is so large that arrangements can be made to ensure a steady flow of cable on the job, thus permitting the high degree of specialization necessary to rapid work.

With regard to pole erection, the figures mentioned in Section V included all the work on the excavation of pole holes, the erection of poles, and back-filling; whereas the details of pole erection by mechanical devices given in Section VII refer to erection only—that is to say, all the holes were opened in advance, and the straightening of the poles and the back-filling were carried out by another gang of men. This record is interesting only as showing what can be done under the very best conditions. It may not have been an economical performance, on account of the large number of holes which required opening in advance. The pole derrick truck is the most popular appliance with the field force, and American engineers consider it to be the greatest money-saver of all the aerial construction plant. On three or four different occasions I witnessed the erection of 40-ft. and 45-ft. poles in alleys in 2 minutes, excluding the time taken by the truck to move from one hole to another. In the case of the 25-ft. poles on a grass margin on country roads, the truck halts only to give sufficient time to place the pole in the hole. A chain is placed round the pole in advance, so that the hook from the derrick can be passed at once through the eye, and the pole is then swung from the derrick and lowered into the hole. For short poles this operation takes less than 1 minute. I am not aware what number of poles per day would be considered to be an average under normal conditions. It is only when a long stretch of route is required that record-making is feasible, and the success then attained is due entirely, in my opinion, to the scientific spirit in which the subject has been approached and the high order of team work which has been developed.

Another point referred to by Sir William Noble is the speed of jointing. I can fully understand doubts being expressed as to the ability of men to work at the rate mentioned, without scamping the job. The high standard attained has been reached after considerable attention to "motion study," combined with the methods detailed in the paper. The men selected for training as jointers (usually helpers who have done good work consistently for a period of 12 months) spend about a month in the school and, before they take over a kit of tools as fully-qualified men, are able to joint 75 pairs an hour. After a few months' practice they can joint 100 pairs an hour quite readily; from 75 to 100 pairs an hour is considered to be the average rate for an average man when working on 10-lb. subscribers' cables under normal conditions, and I checked these rates on various occasions. The speed reached by the most experienced men in one of the associated companies has been given—150 pairs an hour—and I confirmed from actual observation in a jointing school that even this rate could be exceeded for a short time. A jointer, however expert, cannot maintain such high speeds when working on large cables under manhole

conditions for more than probably 1½ to 2 hours, and the men are not called upon to make these exertions except in cases of emergency. The figures are quoted, however, to demonstrate what is accomplished in America by specialization.

Sir William has also referred to the question of aerial cable versus open wires or underground cable; I had purposely avoided in the paper any comparison with the standard practice in this country. In view of the reports on the many advantages of aerial cable which had reached this country, my endeavour was to set out the benefits claimed in the United States and the replies offered by American engineers to various objections.

It is not possible to do more than touch upon some of the main questions raised by Mr. Bartholomew. With regard to the joint use of poles, I did not make a special investigation into the history leading up to the present practice, but I understand that for many years the electric light companies attached their wires to the telephone poles, and two extremely dangerous conditions resulted. First, it required all the ingenuity of the foreman to run open wires over the electric light wires without some risk to his men; and secondly, every time it became necessary for a workman to climb to the cable terminal at the top of the pole it was practically impossible for him to avoid contact with the electric light wires. In those days the number of electric wires and telephone wires was embarrassingly large. Since that time, however, the following revolutionary modifications have been made:—

(1) The wholesale replacement of open-wire lines by underground cables, resulting in the utilization of joint-use poles almost exclusively for distribution purposes.

(2) The placing of all electric light and power wires on the top of the pole, and the telephone wires at least 4 ft. below. (The reason for this is that the electric light wires do not require such frequent attention, and being of a comparatively heavy gauge are not so susceptible to breakage.)

(3) The increase in the spacing of arms carrying telephone lines from 12 to 24 inches, giving ample clearance.

(4) The covering of the electric light wires by at least a triple-braiding weather-proofed insulation.

(5) The adoption of lead-covered distribution cable between poles, and a covered drop-wire for the connection between the cable terminal fitted on the pole and the subscribers' premises.

(6) The placing of strain insulators on the stay wires.

(7) The placing of insulating joints where aerial lead-covered cable is connected with the underground system.

(8) The spread of the "Safety First" movement.

The standard specifications as now laid down by the telephone companies in conjunction with the supply companies are considered by American engineers to afford adequate protection to the interests of the companies concerned and to the public. It should be mentioned that in the residential part of American cities the majority of people have electric light, and the services are generally furnished by overhead conductors. Consequently, without the "joint-use" method there would be an unsightly duplication of pole lines. The municipalities have in many instances insisted upon the use of the same poles by the two utility companies. Present-day practice is such that the employees do not consider they are incurring any risk when working on joint-use poles.

Mr. Bartholomew raises the question whether a pure lead sheath will more readily withstand chemical corrosion than an alloy sheath. I consider it safe to assume that when the change-over to an alloy sheath was made by the American engineers they took the factor of corrosion into account. For ordinary use in ducts, strength and economy are possibly more important than liability to chemical action—an alloy sheath being cheaper than a pure lead sheath for a given strength. Cables installed in vitrified clay or creosoted-wood duct are not subject to the same risk of corrosion as those laid in metal pipes. The object of using an insulating joint at an underground "dip" is to prevent stray currents entering the underground section by the cable sheath in the event of lighting or power wires coming into contact with the aerial section. For the same reason insulating joints are also used wherever aerial cables enter a building. Underground cables subject to electrolytic corrosion by stray currents are, upon entering the central office building, insulated from metallic structures and metallic pipes likely to form a ready path to earth. If this plan is not feasible the continuity of the sheath of the entering cable is broken between the mouth of the duct and the structures or pipes. Mr. Bartholomew also raises a point in connection with the bonding of cable in manholes. As mentioned in the paragraph to which he refers, American engineers do not consider the connection to a buried earth plate reliable. There is a risk of corrosion; and replacements involve taking up a portion of the concrete floor. As the usual lubricant on the sheath of underground cables is considered to be ineffective as a preventive of corrosion, and as the bonding ribbons are not earthed, American engineers are obliged to rely on systematic tests. Periodically—probably once a month—maintenance men visit every part of the underground system to record the readings of both current and voltage leakage between the cable and an earth. These readings show where any leakage is approaching the danger point. An endeavour is then made to locate the source of the trouble.

Captain Hines mentions the ratio of lines to floor space in large office buildings. This is a common way of referring to the density of telephones in America, but the renting area should be taken in preference to floor space. The latter might include corridors, lifts, light-wells, and other unoccupied space. In the financial districts of an American city the number of telephones per 1 000 sq. ft. of renting area would average from 4 to 5, whereas in a commercial district the corresponding figure would probably be from 2 to 3. The sentence in regard to æsthetics quoted by Captain Hines refers to "rear-property lines" and not to main open-wire routes. He would probably be more inclined to the American point of

view if some of these small routes in the alley-ways could be inspected. When telephone circuits alone are carried, the poles are only about 20 ft. high; they are not fitted with arms, and the only connection between them is a small cable with its suspension strand. From each pole there are probably 3 or 4 drop wires radiating in short spans direct to the subscribers' premises, where they are terminated with a minimum number of house fixtures. This arrangement is much more satisfactory than the old "ring-top" method, which admittedly was not good from the æsthetic point of view. Captain Hines deduces from the figures given in the paper for the speed of pulling-in cable, a period of 3 hours for moving from one point to another on 22 occasions. Although the time taken was probably more than 3 hours, I consider that the greatest saving of time effected is in this item. Four men supplied with a Ford box car move in advance of the pulling truck, mount the drums, remove battens, and place the grip on the end of the cable in readiness for installation. This complete cycle of operations is performed in 10 minutes. It is true that additional sets of jacks, spindles, etc., are available, but there is only one motor truck for hauling the cable on the work. The speed of work in this country, as Captain Hines points out, is undoubtedly very good—particularly when performed by hand labour; but given the American conditions—a motor truck and other labour-saving devices, convenient manholes, a plentiful supply of cable, and a willingness on the part of the men to work—the speed would be considerably increased. Captain Hines raises an interesting point with regard to stresses applied to the cable as a result of the speed of drawing-in. I think it will be found that a higher rate of travel results in a lower friction, and consequently less stress on the cable. It was understood that for a full-sized cable (i.e. $2\frac{5}{8}$-inch external diameter) weighing 8 lb. per foot, 600 ft. in length, lubricated with graphite grease and drawn into a $3\frac{1}{4}$-inch vitrified square tile duct by a $\frac{5}{8}$-inch steel rope at a speed of 50 ft. per minute, the stress on the cable would be considerably less than 1 ton. The stress due to pulling a cable by steel wire rope is less than that due to using a $4\frac{1}{2}$-inch hemp rope, as surging is eliminated.

In reply to Captain Carter, present practice does not provide for an earth wire on any type of pole except where a lightning arrester is fitted in conjunction with an aerial loading coil or cable terminal. In this case a No. 6 B. & S. copper wire is run from the arrester to a ground rod driven into the ground about 2 ft. away from the pole. I was informed that little trouble is experienced owing to poles on "through" routes being struck by lightning. The electrose insulator is designed to take two bridle wires at the loading points, one being used for the line to the loading coil, and the other for connection with the lightning arrester always fitted in conjunction with aerial loading coils. At a test-station pole or other bridling point on a high-grade toll circuit only one wire is required; therefore a short piece of spare wire is passed through the vacant hole and made off on the line wire, thus providing a proper support for the insulator. The rope mat shown in Fig. 11 is placed in position only during the installation of the cable. By fixing the suspension strand on the side of the pole by means of clamps [Fig. 8 (*b*)] the cable is normally not in contact with the pole. If there is any possibility of contact at an angle pole, however, the cable is served with a layer of marline immediately adjacent to the pole; this covering is usually found to be sufficient to prevent any injury to the cable sheath. Ring cuts are caused primarily by wind vibration at the point of contact between the cable and the ring. In the centre of the spans the tendency is for the suspension strand, rings and cable to swing together; consequently there is no cutting of the sheath. At the poles where the suspension strand is tightly gripped by the clamp, trouble would be experienced if it were not for the marline ties which take the weight of the cable off the rings on either side. There are three possible movements of an aerial cable which have been carefully measured by recording instruments:—

(*a*) Vertical motion of cable relative to pole.
(*b*) Horizontal motion of cable relative to pole.
(*c*) Torsional motion of cable relative to ring.

I have not heard of the anti-vibration device mentioned by Captain Carter, but this will doubtless be used instead of the marline ties to counteract any movement of the cable. I have to thank Captain Carter for drawing attention to the wind pressure given in the paper; the correct figure should be 70 miles an hour (this correction has since been made). The simultaneous occurrence of an ice deposit at the wind velocity mentioned at zero Fahrenheit is considered to represent the equivalent of any sleet storm conditions that may be encountered. The question of pole erection by motor derrick has been covered in a previous reply, and I need add only that the truck is not manœuvred into position. The driver, through long practice, pulls up his truck exactly at the right point for picking up the pole.

Mr. Green is correct in his assumption that the difference between aerial and underground 10-lb. cable is due to the thickness of the paper used.

The method of counting the number of oscillations in order to obtain the correct tension during the erection of suspension strand is also employed in America when running open-wire lines as described by Mr. Green.

Mr. Hollings refers to his experience of electrostatic charges on telephone wires adjacent to a railway line. Although I cannot say whether similar phenomena have been experienced in America, the occurrence is not altogether novel. The charges appear to be due to the hydro-electric effect of steam under pressure. In a paper * read by Mr. F. Gill, details are given of a case at Glasgow where continuous sparks $\frac{3}{4}$ inch long were obtained at a pressure of 40 000 volts. Under the title of "The Electrostatic Charge of Telegraph Wires by Locomotives," † Mr. R. W. Weightman describes a case closely similar in details to that mentioned by Mr. Hollings. The latter refers to the

* *Journal I.E.E.*, 1902, vol. 32, p. 220.
† *Journal of the Institution of Post Office Electrical Engineers*, 1910, vol. 3, p. 17.

lack of information amongst telephone men as to the various methods of counteracting depreciation of plant under such abnormal conditions as are encountered in the tropics. This deficiency points to the need of more papers on the lines of that read before the Institution by the late Mr. W. L. Preece on "Telephone Troubles in the Tropics." *

It will be convenient to reply to Mr. Peck's inquiries *seriatim*: (1) It is recognized that in course of time the fundamental plan may become inadequate. Consequently at certain periods, depending upon the size of the city, the plan is reviewed in order to accommodate any changes in the art, alterations in cost, or errors in estimating the growth of the business, either in direction or amount. The plan can then be used as a guide whenever any important extension of plant is contemplated. (2) The provision of miscellaneous circuits is referred to in the reply to Mr. Shackleton.

* *Journal I.E.E.*, 1915, vol. 53, p. 545.

(3) The question of busbar voltage is outside the scope of the paper. Briefly, however, the practice in this country (for Western Electric equipment) is substantially the same as in America; that is to say, the nominal voltage for central-battery exchanges is 24, the lowest limit being 19½ volts. In regard to the supply of power to private branch exchanges, the policy adopted is decided by local conditions, as in this country. (4) Where more than one 10 000-line unit is accommodated in a single building, the standard practice seems to be to arrange the switchboard equipment on various floors, but to combine the cable plant, main frames and power plant. Economies in floor space and plant are thus effected. (5) The practice of fitting local-battery instruments on a central-battery system is, so far as I am aware, adopted on long rural lines where the current supply to the transmitter from the central battery would be insufficient for good transmission.

North-Eastern Centre, at Newcastle, 14 November, 1921.

Mr. J. R. M. Elliott: With regard to the design of open-line plant, the climatic conditions in this country are so different from those in America that a higher standard of construction and design has always been regarded as necessary in England and, from the slides shown by the author and from his description of American methods, there would appear to be little doubt that such is the case. It was known before the war that in the United States the use of mechanical appliances in the construction of open and underground lines was regarded favourably, and that since the war there had been very great development in their use, but we were not, perhaps, prepared to hear that by their application a single gang of 8 men and a foreman would erect as many as 300 poles in an 8-hour day. This, in addition to some of the other performances to which the author refers, makes constructional efforts in this country appear insignificant, and there is no doubt much to be learned from America, where the development of the telephone service has been greater than in any other country in the world. One of the factors which must have contributed largely to the adoption in the United States of mechanical appliances is the low cost of petrol there, but this is no reason why we in this country should not at least attempt the experiment of trying the American appliances and comparing the costs of conducting work by American methods with those of our own. We have unit maintenance and unit construction figures of costs and there would be no difficulty in making an accurate comparison. I do not for one moment deprecate the use of mechanical appliances —indeed, I am strongly in favour of their employment— but the question of cost is the vital factor. With the low costs for petrol and for machinery and the high charges for salaries and wages of officials and workmen in America as compared with the high costs for petrol and machinery and lower charges for salaries and wages in this country, it must not be taken for granted that the wholesale application of American practice in this country will enable our standard of construction to be carried out in a cheaper manner. It is interesting to hear that experiments are being conducted with a view to the introduction of 3½lb. conductors for cables. The manufacturers may have no difficulty in drawing down to this gauge, but breakages may occur in laying up the pairs. Possibly the greatest difficulty may arise when the jointers' operations commence. Can the author say whether the concrete belt sometimes provided around poles at the ground line is liable to chipping? A belt of this kind, if continued 5 or 6 ft. up the pole, would permit painting in cases where we now have to fix lagging and might be more economical. Does not the restricted use of pole steps cause inconvenience? In cases where, say, only one arm is fixed, it will be necessary for a workman to obtain a ladder when any sustained operation is necessary, as he could not be expected to hold himself in position on his climbers for a long period. The absence of facilities for tightening stays must lead to considerable cost after a storm, as it would appear that there is no other alternative but to undo the stay wire at the top of the rod and make it off again whenever a stay is drawn or becomes loose. Locust-wood insulator pins must break oftener than would be the case if steel or iron bolts were used. Is not the operation of extracting broken pins, and the nails by which they are held in place, more costly than the methods of supporting insulators adopted in this country? The joint use of poles for telephone and power distribution has not been looked upon with favour in England. Many of our telegraph circuits, running on the same poles as telephone wires, are worked at a pressure of 120 volts and, beyond the ordinary precautions in the matter of fuses, no protection is considered to be necessary. It would, therefore, appear that little danger is to be apprehended from low-voltage power circuits. To accommodate high-tension circuits on telephone poles is, however, another matter, and I am afraid that telephone workmen unaccustomed to power work would run grave risks if the practice of running two classes of conductor were introduced.

Providing a concrete foundation for underground ducts and sometimes applying a top cover of the same material for protection, appears to be an expensive method to adopt. I notice that experiments are at present being made with self-aligning ducts laid in accordance with the methods followed in this country. Unless the conditions are totally different in America there is no reason why the experiment should not be a success, as in this country it is not often the case that ducts are damaged, certainly not frequently enough to justify the provision of a concrete bed. I am not clear as to whether the jointers' test-boards described on page 103 are sealed up in the joint on conclusion of the jointing operations. If this be so, it occurs to me that the joint will assume rather bulky proportions. What advantage has this arrangement over the method of using paper sleeves? The use of motor transport in connection with the telephone systems employed in America appears to be on an extensive scale as compared with the relatively trifling extent to which it is employed in England. This is no doubt due in the first instance to the enormous development of the telephone in the States, and, in the second case, to low costs for petrol and for motor transport. It is, nevertheless, apparent that transport facilities associated with the construction and maintenance of the telephone system in this country have only commenced to be regarded with favour, and the tardy manner in which their distribution is taking place affords an indication of the tendency to ignore up-to-date practice. The author explains that motor cycles are used to a limited extent for maintenance purposes. This is somewhat surprising, as motor-cycle combinations supplied for the use of linemen with long lengths of line to patrol have, in this country, been found of great service. The author showed a slide of a 3-ton construction lorry, with ladders fixed to the sides. Can he give the maximum length of ladders carried in this way and say if any of these ladders are of the telescopic pattern? The author states that, prior to the war, the average duration of faults in large cities was about 2 hours. It would be interesting to learn the present average duration. This is largely a matter of the number of men employed per unit of plant and, since the author has referred to the point, it would have been most instructive if he had given particulars of the loads apportioned to maintenance men, i.e. those whose duties are confined almost exclusively to the removal of faults.

Mr. C. Whillis: I was surprised to learn from the paper that, if very small allowances be made for racial characteristics, geographical conditions, and company as against Government control, the basic organization in America is almost identical with that in this country. In that connection I should like to ask the author what division is responsible for the installation of comparatively small units of internal plant. His staff diagrams seem to indicate that all exchange equipments, no matter how small, are installed by the Western Electric Company. Development studies appear to be made in a very similar way to that adopted in this country, but in the design and lay-out of plant I notice an interesting detail. Fig. 2 appears to indicate that the same pairs are taken out into the stubs at more than one point on the main cable, in order that alternative distribution may be effected. This practice was abandoned in England a number of years ago, but in very fast-growing areas it is probably a good arrangement and one that makes for flexibility. It is perhaps dangerous to criticize adversely anything that one has not seen, but the author's description of open-line work leads me to the conclusion that we, in this country, have nothing to learn from America in the way of open construction. Indeed, it appears that the only reasons why the Americans do not experience serious trouble are that their open lines carry comparatively few wires and that their spans are only about half the length of those in this country. Timber is apparently very cheap in America. Arm and insulator fittings seem to be very crude, and such appliances as glass insulators and wooden insulator pins would be of no use in this damp climate. Boring tools for pole and stay holes were tried here very many years ago and abandoned because, among other reasons, very few holes could be bored without large stones being met with, and where there was soft digging the earth fell in from the sides of the holes before the poles and stays could be placed in position. Perhaps American geological formations are more suitable in this respect. Aerial cable erection practice seems sound, but I am surprised to notice from Fig. 11 (*c*) that cables are taken round the poles on the outside of angles. This practice has been the cause of serious trouble here and, with the short distance of the suspension wire from the poles, I do not quite understand how abrasion of the cable is prevented at sharp angles. Short spans for aerial cables are an absolute necessity, and probably this accounts for the successful use of such cables in America as compared with indifferent results here. The insulating joint illustrated in Fig. 14 (*b*) might be quite satisfactory in a dry climate, but I am afraid it would cause trouble in this country. In Fig. 10 (*a*) it would appear that the hooks of the suspender are shown reversed. Except for the labour-saving devices, underground practice in America is not dissimilar to that in this country, but I prefer the Post Office type of self-aligning multiple duct to the square type. Do not the aligning dowels make the line somewhat inflexible? The author may be interested to know that the method of jointing shown in Fig. 24 is fairly common practice in this district. The method of suspension illustrated in Fig. 23 is, in my opinion, open to objection. The life of the suspending wire may be very short in some situations. In any case it will certainly be less than that of the cables, and renewal is impossible. The method of lead tacks at intermediate openings is preferable if it can be arranged. The description of labour-saving devices is very interesting and instructive, but I wonder what other administrations would say if the trenching machine were used by the Post Office on even comparatively remote roads in the United Kingdom. The rates of progress quoted are somewhat astounding and, if all conditions are comparable, they form a serious indictment against the organization and workmen of this country.

Mr. C. Vernier: I am particularly interested in the suspension of lead-sheathed cables described in the

paper, and am surprised at the large size of cables handled in this manner. Some 10 years ago or more we were faced with the same problem, as telephone circuits in connection with power transmission lines, in order to provide satisfactory service, should not be open wires, because otherwise they are liable to be brought down in storms just at the time they are most likely to be required, and, if erected in the vicinity of the power line, to have dangerous voltages induced in them. Our first attempts at suspending such telephone cables, which are of the usual type and lead-sheathed, led to somewhat disastrous results, the cable sheaths cracking all to pieces in a very short time. We therefore had to find an independent solution of the problem, all the available information appearing to show that this had been the common experience of others who had tried similar suspensions. The method we now adopt is very similar to that used on these large cables in America, but our problem was, if anything, more difficult, in that our cables are small compared with those referred to in the paper, usually containing only 4 and 8 pairs per cable. It has been found that the essentials for successful suspension are:—(1) Short hangers, so that the cable and suspension wire swing absolutely together; (2) prevention of the displacement of hangers along the suspension wire; (3) the provision of some hardening material (usually tin) in the lead sheath, and (4) the carrying of the cable as horizontal as possible. This method was described in Mr. Welbourn's paper,* and an illustration of the "Elder" patent hangers, made of leather, designed for this purpose, was also given. We now have over 100 miles of such cables suspended in this manner which have given excellent results during the past 10 years in all sorts of weather conditions. The spans are usually 240 ft., but a number of spans of 525 ft. have given equally good results. The hangers are spaced 12 inches apart. I should have thought that the ring hangers shown in Fig. 10 of the present paper might lead to trouble due to the small and hard bearing surfaces available for supporting the cable, and also to their being so much larger than the cable that it can roll about in them. Perhaps the last point does not arise so much with the heavy cables erected in America, but these would accentuate the former. We much prefer leather hangers which give a wide, soft surface and damp out vibration. Our practice in erecting the cable is to run it out along the ground, and to lower two or three spans of the suspension wire after it has been roughly sagged. The cable is then attached to it with the suspenders, and each span is raised to its point of attachment by means of pulley blocks. Special precautions are taken at angles, where the cables are invariably taken on the inside of the angle, and not as shown in Fig. 11, the latter method being very unworkmanlike. I have for some time been inquiring into the use of mechanical excavators, but so far these appear to be little suited to the conditions met with in this country, where roads in rural districts to which such appliances are, of necessity, restricted on account of obstruction, are usually very narrow, and necessitate a trench being cut close to hedge lines or fences. The most promising of all such devices which I have met is the Mangall-Irving earth borer. This, I am glad to say, is a British invention and a most ingenious device with interesting possibilities.

* "British Practice in the Construction of High-tension Overhead Transmission Lines," *Journal I.E.E.*, 1914, vol. 52, p. 190.

Mr. F. G. C. Baldwin: The author has, I think, been wise in confining his paper to a description of American methods, and in refraining from drawing comparisons between American and British methods. While it must be admitted that America is the home of the telephone, and that it has been developed there by a high standard of technical skill and commercial enterprise in which the factors co-operation and organization figure very largely, it must not be forgotten that in the early stages of the telegraph and telephone a good deal of pioneer work was done here, and it seems probable that in some measure Americans have been considerably assisted by individual labour in this country. Before reading the paper I was under the impression that the use of antimony as an alloy with lead for cable sheaths was tried some years ago and given up owing to the tendency to brittleness which the use of antimony engendered. Apparently this difficulty has now been overcome. On page 91 the author refers to the almost invariable use for toll lines of 435-lb. or 173-lb. hard drawn copper wire. Is it to be understood that 435-lb. wire is the heaviest type of copper wire used for long-distance circuits in America? For such long lines as exist in that country one would have thought that much heavier wires would in many cases be necessary. Can the author say whether the application of the thermionic valve in the production of telephone repeaters has already contributed to a reduction in gauge of overhead conductors? On the same page there is a reference to the mutual advantages secured by the joint use of poles for telephone and electric supply wires. In this country I am afraid that both administrations concerned would consider that mutual disadvantages accrue from such a practice. On page 96 the author refers to the W.E. "No. 14" type of cable terminal. These cable terminals were successfully used for some years by the National Telephone Co. They were most convenient, but had the disadvantage that condensation was apt to occur on the porcelain blocks in which the terminals were fitted, with an attendant loss in insulation. Further, in industrial neighbourhoods corrosion of the terminals, due to the presence of acid fumes in the atmosphere, in combination with moisture, was experienced; their use has now been abandoned. I understand, however, that terminals of this type have been considerably improved and, if this is so, I think it would add to the value of the paper if, in his reply to the discussion, the author would give detailed particulars of the latest terminal of this type. The No. 8 terminal was also used in this country to a limited extent, but the No. 14 type was regarded as being infinitely superior. The use of aerial cable is much more prevalent in America than in this country, and it seems highly probable that the advantages mentioned on page 97 are much more applicable to American conditions than to British. During the period 1900 to 1911 a large amount of dry-core lead-covered cable was erected in this country. A good

deal of this has since been recovered, and examination at the time of recovery revealed the fact that even the comparatively soft pigskin slings had caused serious indentations in the lead and, incidentally, that crystallization of the lead sheath appeared to be fairly general. It would seem reasonable to suppose that the type of ring illustrated in Fig. 10 would be much more likely to cut into the cable than soft pigskin leather, but the author says this is not the case. I shall be glad if he can say in what way indentation of the lead sheath has been overcome. I was particularly interested in the methods adopted by American engineers for leading-in cables at exchanges. I think that the method adopted in 1912 at the Victoria Exchange in London (see Fig. B) is superior to any hitherto employed in this country. It will be seen that the cables, instead of being carried along the walls, are supported in an iron racking running from end to end of the cable chamber

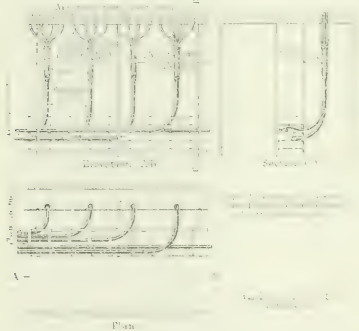

Fig. B.—Method of leading main cables into large telephone exchanges.

beneath the main frame, and that provision is made on this rack for any necessary crossing of cables. There is perhaps little to choose between the two methods, but so far as appearances go the method employed at the Victoria Exchange seems superior. The boiling-out process in conjunction with woven cotton sleeves was adopted when the first dry-core cable was laid in this country in 1890. This practice was soon abandoned in favour of desiccation by means of hot lime. Eventually desiccation by brazier or lamp was adopted (about 1896) and continued generally in force until a year or two ago, when boiling-out began to be practised to some extent. I am not satisfied that the boiling-out process is as satisfactory as it is claimed to be. Up to the present our experience has not been that superior insulation can be absolutely relied upon by the adoption of this process in preference to any other. The reason is not apparent, but is probably due either to the lack of appreciation of the requisite temperature, or to want of experience on the part of jointers in applying the wax. I shall be glad if the author will say whether, in his opinion, the use of molten wax is distinctly preferable to drying out by means of brazier or lamp, and whether a very much better insulation can be relied upon. Further, it is probable that the difference between the atmosphere of this country and that of America may have some effect on the process. It must be remembered that in America there does not exist the congestion in the streets and highways which obtains in many of the thoroughfares in this country. In many cases, owing to congestion, the positions of the joints are such that boiling-out cannot conveniently be resorted to, and it therefore seems to me undesirable to employ two independent methods, necessitating the retention and transport of two different sets or appliances for the one purpose. I should be glad if the author would confirm his two figures under par. (*h*) on page 103; the jointing of 100 pairs, not to mention 150 pairs, an hour per jointer represents an expenditure

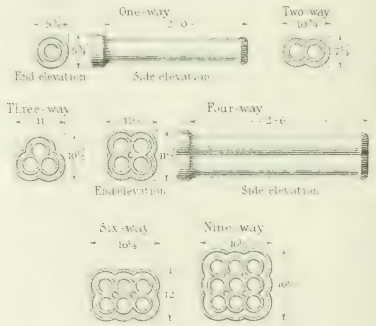

Fig. C.—Earthenware conduits used by British Post Office.

of only 36 seconds per pair of wires jointed, which seems to me a very highly satisfactory performance indeed. Will the author give us his personal opinion as to the reasons for the much higher rate of working which has been attained in America? Has the absence of cotton wrapping anything to do with it, or is the reason for it to be found in the first paragraph of his Conclusion on page 110? Under the heading "Terminating Cable" it is stated that cables for subscribers' lines are terminated by means of silk and cotton-insulated cable, and that the joint intervening between the two types of cable is not filled in by impregnating material. Will the author say whether the silk and cotton cable is dry or impregnated, and, if the former, what means are taken to prevent the penetration to the paper core of moisture absorbed from the air? In this country a great deal of trouble is experienced in the maintenance of a satisfactory standard of insulation at the silk and cotton ends, and the question of the termination of paper-core cables should receive serious

attention. Under "House Cabling" the author describes a system whereby at large office buildings flexibility is secured by diverting a proportion of the incoming circuits through a distribution case or cross-connecting field at a point near where the cable enters the building. Such a method was employed in London in 1912, with eminently satisfactory results. In spite of the author's evidently favourable view of American drop wiring, I cannot but deprecate its employment in this country. To me it appears to resemble too much some of those very ugly overhead electric light wiring systems used in many of our small towns and villages. The use of the overhead construction gang truck described in Section VI would be justified in this country if the demands for telephone service were more numerous. As regards mechanical and labour-saving devices, the whole of the appliances illustrated in the paper are such as can be justified only on works of an extensive character. The development of the telephone in this country has not been such as to justify the undertaking of works of such magnitude as apparently obtain in America, and there is therefore a smaller field for the adoption of labour-saving machinery. In connection with the removal of discarded poles, however, an American appliance has been employed in this district by which poles up to about 40 ft. in height may be bodily withdrawn from the ground without excavation. The use of this tool has reduced by about 65 per cent the labour necessary for carrying out such work. Ducts used in this country differ considerably from those shown in Fig. 16. Fig. C illustrates the type of duct now standard, and it will be seen that the alignment is secured by the use of spigot and socket. The use of concrete is not general.

Mr. G. E. Gilpin: In view of the fact that the poles are not earth-wired and are used for carrying electric light wires along with the subscribers' circuits which are fixed to single-shed insulators, it would be of interest if the author would express his opinion as regards the efficiency of the service generally in comparison with the service provided in this country. Are intercommunication facilities provided between the subscribers of the various telephone companies in America, and, if so, are all the various systems of working alike? If different systems of working are in use, are the speaking connections free from noises, cutting off, violent cracks in the telephone receivers, and interferences during speech by the operators of the various companies concerned? I should be glad if the author would say if superimposing is satisfactory when carried out on practically all long toll circuits. Presumably with these arrangements there are no automatic calling or clearing devices. If this is so, I do not understand how such a system of working can be entirely satisfactory from an engineering point of view. I am rather doubtful if such arrangements would be profitable. Since one faulty wire results usually in the stoppage of three circuits, and if the calling and clearing signals are not automatic, there is a certain loss of revenue through the time lost in manual signalling. The author states in one case that the sheathing of the lead cables is cut to prevent the flow of current along the sheath, and yet when referring to "bonding" he mentions that owing to electrolysis *all* cables are bonded together in manholes, etc. I should be glad of some further explanation of this matter. Is it preferable to bond all cables and pipes together or to cut and isolate electrically the sheathing as much as possible? In regard to aerial cables, I should like to know whether the suspender wires are earthed, and whether there is any difficulty due to the sheathing being punctured by lightning. In regard to staff organization, what is the relationship between the Engineer-in-Chief and the General Superintendent of Traffic? Does the Chief Engineer decide what type or systems of working should be provided for? Finally, is the General Manager a technical or commercial official?

Captain F. W. Gaskins: With regard to development studies, referred to in Section III, I should like to point out that a very similar procedure has been in force in this country for many years, except that we do not go quite so fully into details. Particulars of all existing plant are prepared by the Engineering Staff, development is estimated for periods of 5, 10, 15 and 20 years by the Commercial Staff, and then the engineers design the plant lay-out for 10 to 20 years ahead, according to the economics of each individual scheme. In this District, extending from Berwick to Whitby, since the end of the war we have dealt with something like 40 development schemes, many of which are already completed, and this work is in progress throughout the country. On page 88 the author states: "The question of the actual type of plant to be adopted is always considered from the standpoint of economy." I should like to know whether lead-covered paper-core cables, either bare or protected by means of a wrapping of jute and compound, have ever been used in the United States without conduits, and if so with what result. At the bottom of the same page a 1 500-pair $3\frac{1}{4}$ lb. cable is referred to. Copper wire of this size is very light for this kind of work, but although meeting the electrical requirements for short lines the governing factors are its ability to withstand the applied strains during manufacture and subsequent handling. It must be left to experiment and experience to prove whether it is practicable or not. On the same page a colour scheme is outlined for subscribers' cables. In the days of the National Telephone Company I recommended a similar scheme, but giving to each 50 pairs its distinctive colour. This method has never been adopted in this country, although it appears to me to have great advantages. In Fig. 2 the lay-out appears to be most complicated and I should be glad to have some further explanation of its application. Apparently three sets of numbering are in use, viz. distribution point pair numbers, assuming each distribution pole to be a separate numbering unit, the branch cable pair numbers, and the stub or main cable pair numbers, but it is not clear if this is the case. The system of co-operation between the commercial and engineering staffs, referred to on page 90, is also in use in this country, and is very necessary for the reasons mentioned. With regard to Section V, I should like to ask whether the author has any figures

of the average life of the poles referred to. It will be observed that the length of span stated on page 90 is much less than in this country, and therefore a larger number of poles, pole fittings and, consequently, considerably more labour for erecting will be necessary, which should be kept in mind when estimating comparative construction costs. It is somewhat surprising to read on page 91 that 40-lb. bronze wire is so little used, as it is our chief conductor for subscribers' circuits, and is only replaced by 70-lb. bronze or 100-lb. copper where transmission requirements necessitate this course. Will the author say if there is some special reason for this procedure? Referring to the joint use of poles by electric supply and telephone authorities, perhaps the author could give some information with regard to the voltage in use on the power circuits. In this country this practice is considered to be very undesirable and is avoided as a general rule. The methods of construction of aerial cable routes appear to have been designed on sound and reliable lines. It is not mentioned in the paper, but no doubt periodical inspections are made in order that any minor repairs or adjustments can be carried out before any trouble occurs. I should like to ask the author whether any figures of the length of life of the large lead-covered aerial cables are available; also whether it can be definitely stated that the "Bonita" rings do not cut into the cable after a few years' use, due to vibration of the suspender wire, swinging in the wind, etc. With regard to loading coils, referred to on page 96, it is understood that these coils are now being made with iron-dust cores. As this is an innovation any further available information would be valuable. Also, it would be useful to know the approximate efficiencies of coils with this type of core as against those with other types of core. On page 102 the author states that pliers are not used by the jointers, scissors being more easily handled. Does this mean that the end of the wire twist is cut off with scissors and, if so, are they not a special type of scissors? It has occurred to me that a further saving in time and also of fatigue to the jointer could be effected by breaking off the end of the twist instead of cutting it off: this could easily be done by giving a few extra turns to the wires whilst tightly gripped between the thumb and forefinger of the left hand (see Fig 24 and especially the fourth operation). I intend to experiment with this method with a view, if successful, to its adoption as standard practice for jointing small conductors. There are, of course, several ways of dividing or terminating large lead-covered paper-core cables, but it appears to me that the British Post Office method, viz. the "divided joint," is better than that shown in Fig. 25. A 20-inch sleeve to accommodate a 900-pair joint seems to be very short, as against the 30-inch × 4-inch sleeve generally used here for the larger joints. The speed of jointing referred to on page 103 is very high; can the author say, from his personal knowledge, that this performance has actually been achieved? No mention is made in the paper of conductivity or cross-talk tests on subscribers' cables during, or on completion of, laying. Are such tests made? Presumably the class of wire used for drop wiring is vulcanized indiarubber or guttapercha, containing a suspending wire in its make-up. The rate of pole erecting, even allowing for the short spans, i.e. the distance between poles, taxes the credulity of those who have had experience of pole erecting in this country, and the erection of poles at the rate of 300 per 8-hour day or 1·6 minute per pole would, I am afraid, have to be seen to be believed. I consider the provision of spare conduits on a liberal scale to be a very wise procedure and one which can be usefully followed.

Mr. J. Peel: I should like to ask the author to give some information on the following points. (1) What description of wood is used for pole arms? (2) In the case of aerial cable drawn across a 6 000-ft. gorge is the cable jointed prior to erection? If so, how do the joints pass through the wire cable hangers? If not, how are the successive lengths drawn over the same track to permit jointing, and how is creeping prevented? (3) Is it quite certain that the cable sheath was not damaged by being drawn through such a large number of the cable hangers? (4) On underground work what is the necessity for the very large manholes in general use? Is not the cost found to be prohibitive? (5) What is the average rate of progress in laying full-sized cable in ordinary circumstances, as compared with the record progress of 44 drums of cable per day, laid by 20 men? Although the use of power digging and trenching for cable, pole and stay work would be quite suitable for stretches of country roads where few artificial obstructions are encountered, in this country the quantity of pipes and cables laid under every roadway and footway would effectually preclude the use of such devices.

Mr. H. Kitchen (*communicated*): It is not clear from the author's remarks under "Design and Layout of Plant" what standard is used for telephonic speech. Assuming that $3\frac{1}{2}$ lb. cable is introduced, it will be necessary to limit its use to within comparatively short distances of the exchange to keep within the breakdown resistance. What circuit limitations are imposed in the United States? I understand that trunk or long toll lines are connected to specially rented telephones only, and that the ordinary exchange instruments are used solely for local traffic. If this is so, it is evident that there is not the need for such a high-grade local circuit as in Great Britain, where every telephone is capable of communicating with any other instrument within the United Kingdom. It is surprising that with such simple and proved preservative methods in use all over the world American telephone engineers do not have all their poles suitably treated before erection. Even if the timber is cheap, renewal costs must add very considerably to the plant upkeep. Creosoted timber in this country costs about 20 per cent more than similar timber not so treated. The conservation of the world's timber supply ought to receive some consideration in the economics of American telephone administration. In dealing with wayleaves the lump-sum payment no doubt appeals very much both to the telephone companies and to the grantors. Can the author quote the average payment per pole for urban and rural districts, and say what happens when there is a change of ownership? Presumably the new owner is not compelled to allow the poles to

remain in position for all time without compensation. The number of poles used on main lines in America is approximately 100 per cent more than in Great Britain. This increases the labour costs of building 100 per cent and the cost of material very considerably. Can the author show how this very heavy additional cost is justified in comparison with the service in this country? Unless the weather conditions are very much more severe in the United States than in the United Kingdom, I cannot see the necessity for such short spans. There will no doubt be a saving in day-to-day upkeep, but pole, arm and insulator renewals will apparently more than balance the saving in ordinary maintenance. Moreover, renewal work whilst in progress does not improve the efficiency of a line.

[The author's reply to this discussion will be published later.]

Liverpool Sub-Centre, at Liverpool, 21 November, 1921.

Mr. A. J. Eames: Although no attempt has been made in the paper to compare American methods with those of other countries, I do not think that telephone engineers in this country can readily avoid comparing American and British practices. Obviously any indiscriminate criticism of American methods would be very inappropriate, as the greatly varying conditions, such as those due to climate, distance, space and the character of the highways, make differences inevitable. Other factors, such as the life of plant, annual maintenance charges and depreciation, also enter into the question. The wider open spaces in America permit of the design of plant of a strictly utilitarian type, and ugliness is not so conspicuous. In this country much closer attention has to be given to the amenities. On account of the relatively greater humidity of the British climate, for example, the use of glass insulators with wooden spindles mentioned on page 91 and the drop wiring system mentioned on 107, would be unsatisfactory in England, owing to insulation losses. In Section II no reference is made to any scheme for the technical training of the junior grades of the engineering staff. On the whole, the work is organized on similar lines in this country. Development studies in America proceed on almost identical lines. Some of the information sought for may be considered to be of too searching a character; but experience strongly confirms that statistics of a very complete kind are essential to avoid waste of capital, or costly and premature replacements of serviceable plant. The planning of schemes for telephone development is also treated in the same way. The provision of cable stubs at suitable branching-off points along the main cable is a useful device for obtaining flexibility in cable-pair distribution. Teeing-on at the main cable joint is a disadvantage which would, perhaps, be better avoided by looping pairs through the stub cable. It is necessary to guard against any additional liability in regard to faults. I am unable to accept without some reservation the suggestion that the arrangement prevents faults. The risk is, to some extent, removed from the main cable joint to the stub cable. The most striking difference is the very extensive use of aerial cables in America, and the author will no doubt agree that this is due in a very large measure to the favourable economic conditions. The method of erecting aerial cables described in Section V is generally sound, particularly in regard to the short spans. Timber is evidently cheap and plentiful in the United States; indeed, the short spans arranged for all classes of overhead lines facilitate the substitution of cable for bare wires when necessary on account of development. I have only one or two small exceptions to make. The practice of driving two bolts transversely through the pole to secure the clamp, instead of carrying a band round it, unnecessarily weakens the pole. Greater care has to be taken of telephone poles in this country, as the majority are imported and are extremely costly. For these reasons it is necessary to set them farther apart. The opinion is rather widely held that marline, a vegetable substance, has deleterious effects on lead sheathings in damp atmospheres. Rawhide strips for hanging and tying up the cable to the suspender wire are preferred. I should be glad to know the author's opinion on the subject. The metal rings would also tend in time to cut the cable sheathing, and, it is thought, would prove very unsatisfactory in neighbourhoods such as Manchester and Liverpool where the air is to a considerable extent impregnated with chemical products. The 10-wire arms shown in Fig. 3 would not be very adaptable here, as the poles have to be spaced further apart, and the wires would be thrown into trees. It would appear that routes in America can be erected in straight lines and construction is thereby simplified. The 24-inch arm spacing would very seriously limit the wire-carrying capacity of poles, but must considerably minimize the risk of faults if the wires are properly regulated. I should be glad if the author would state the reasons why bronze wire is so little used in America. Such wire is very suitable for the conditions met with here, being economical to erect in cases where direct underground leading-in would be too costly. The electrose insulator shown in Fig. 5 is a novelty to me. An insulator appears to be suspended from the line wire, and swaying and vibration seem likely to cause trouble with the bridle-wire connections. The method of transposition shown in Fig. 6 is, of course, only practicable when the arms are spaced 24 inches apart, and other means are necessary in this country. On page 93 a running board is referred to. Is this intended for running out, say, 4 wires at a time? The short spans and the transposition system would facilitate this. I should like to know whether experience proves that the insulating joint (see Fig. 14) in the lead cable on the pole is really effective, and on what grounds this arrangement has been adopted instead of earth bonding. It is suggested that the real reason for placing concrete round the ducts (see Fig. 16) is to retain this form of multiple ducts in true alignment, apart from the protection afforded against external damage. On page 107 a description of the material

covering the wire used for drop wiring has been omitted, although on page 106 there is a caution against confusing drop wiring with bridle wire, details of which are given. It is hardly likely that this method of wiring would be suitable in this country, although much depends upon the composition of the material. The account given of the mechanical and labour-saving devices in Section VII is of great interest, but again the conditions must be extremely favourable in America, where there are far fewer obstructions in the sub-soil. I am afraid that the use of such machinery on English highways would result in many claims being made for damage to gas, water and other mains, as well as for damage to property.

Mr. C. F. Bolton: On page 98 under "Conduit Routes" the author states that alignment is maintained at butted conduit joints by means of two steel dowel pins. Does this mean that in the case of either a 2-way or 9-way duct it is found that the two pins are sufficient to ensure the necessary stiffness as well as alignment at joints? I am interested to hear that ducts are laid on a 4-inch concrete foundation, as I am of the opinion that this is a most important point, especially in cases where the external diameter of the cable to be installed approximates to that of the internal diameter of the duct. My experience has been that when the duct line is laid without a rigid bed (I am referring here to glazed earthenware ducts with spigot and socket joints as used by the British Post Office) irregularities of level may occur at pipe joints, and an accumulation of these irregularities in a duct section constitutes a serious source of friction when a length of cable is being drawn in, particularly when the conditions already stated obtain. Under these conditions the sheathing of the cable is subjected to very great strain, and to prevent this I consider that the provision of a concrete bed for obtaining correct level would be well repaid. In the case of underground balanced trunk cabling the speed of drawing-in determines, within certain limits, the rate of progress of the whole work, and it will be obvious that where difficulties are experienced in drawing-in lengths the entire organization is thrown out of joint, with the result that the work of jointers and testers is held up, thus involving a serious monetary loss. I understand that even when concrete is dispensed with in American practice a 1-inch plank is used for the ducts to rest on, to ensure correct level and alignment. Can the author confirm this? With reference to the statement that experiments are at present being made in America to ascertain whether self-aligning ducts fitted with spigot and socket joints as used in this country are liable to be damaged when laid at normal depths, I have read of a case which occurred in America of 500 ft. of the top ducts of a conduit route laid without concrete being crushed in by a steam roller working on the surface 24 inches above. The practice of always providing a draw wire in one duct when a conduit line is installed is sound, as it may be assumed that cabling operations will follow immediately after a conduit route is installed. Much time and expense is therefore saved by precluding the necessity of rodding operations. The author states that concrete is now more frequently used in manhole construction. This is no doubt cheaper when a clear run can be obtained, but I imagine that in congested street areas where pipes, etc., have unavoidably to pass through the manhole, concrete construction would be more expensive than brick owing to the difficulty of fixing the shuttering. The practice of providing entry in the centre of the manhole in all cases is excellent, and the provision of a ladder seems to me to be of primary importance. Where no ladder is provided there is a great tendency for men to use the cable as a step when entering or leaving the manhole. The installation of racks during manhole construction is also an important point, as it is imperative that the cabling gang have means of supporting the ends of the cable after drawing-in, to avoid kinking at the duct mouth. No mention is made in the paper of any precautions for the draining of manholes, but I suppose that where possible such precautions are taken. As stated on page 99 under "Installation of Cable in Ducts," progress in drawing-in must undoubtedly be expedited by the adoption of standard manhole construction. Much time can be lost in adapting gear at the hauling end to manholes of varied construction. I note that a $\frac{5}{8}$-inch steel wire rope is used for drawing-in purposes. I have always been of the opinion that a manilla rope is unsuitable for this purpose, owing to the fact that the rope stretches to a great extent before the cable is moved. When the latter occurs the cable enters the duct with a rush, and the cable is liable to be kinked and damaged at the feeding end. I note that American engineers consider that any lubricant used acts as a lubricant only and does not form an effective preservative against chemical or electrical action on the lead sheath. This seems probable in view of the fact that much of the lubricant must be scraped off the sheathing at various points during drawing-in operations. I should like to know whether the metal duct shields which are inserted under the cable at the mouth of the duct are permanently left in position. A good protection of this sort is obtained by using a small piece of sheathing under the cable at the duct mouth. Can the author give fuller particulars in regard to the statement on page 100 that a length of 4 miles of full-size cable was drawn-in in one day by a gang of 20 men working for 10 hours? Assuming the standard length to be 176 yards and the speed of drawing-in to be 50 ft. per minute, each length would require $10\frac{1}{2}$ minutes for this operation. The total time available is 600 minutes and, assuming only 40 drums to be installed, the time available per drum is 15 minutes. There is therefore a balance of $4\frac{1}{2}$ minutes for moving from one manhole to another, setting up the gear at the hauling end, drawing-in the $\frac{5}{8}$-inch steel wire rope, making connection to the cable grip, etc. This seems a remarkably small time allowance for all these operations, and the question naturally suggests itself as to how many motor winches were used. Did the operations cover a distance of 4 miles from point to point, or were several cables drawn-in at one position, thus doing away with the necessity of moving the motor winch after every two pulls? The figures given on page 103 under "Speed of Jointing," are indeed remarkable and I should be glad if the author could give us as a comparison the average speed of jointing a similar

cable by British Post Office jointers. I note that as a general rule air pressure-testing is not carried out. It seems especially imperative that this should be done in the case of underground balanced trunk lines, as should it be found necessary to withdraw a length owing to faulty plumbing or sheathing much time and expense would be involved in breaking up the loading coil section to balance in the new length. I am also surprised to note that no attempt is made to remedy low insulation by means of desiccating, as very good results can undoubtedly be obtained if desiccation is properly carried out. A disadvantage of waxing joints which is not mentioned by the author is that the colours of the marking papers are to a large extent neutralized by waxing. When jointing a balanced trunk cable according to a pre-arranged selection scheme this might lead to serious errors, especially when working in a manhole in artificial light. This would necessitate opening the joint and correcting the errors in question, always a costly operation. I believe that the speed of 50 ft. per minute stated on page 109 for drawing-in cable is higher than that usually adopted by the British Post Office. I am of the opinion that this speed can be quite safely used, provided the cable can be suitably lubricated. In this connection it would be interesting to know whether any form of mechanical device is adopted for lubricating cables in America.

Mr. A. J. Pratt: Does Fig. 2 represent the complete lay-out and final arrangement, with the exception that the provision of the 900-pair cable is deferred? On page 104 the statement is made: "If after two or three years it is found that the original distribution of the circuits requires modification, it is a comparatively simple matter to open the stub cable and rearrange the circuits for a further period." The author doubtless refers here to the opening of the stub cables and the rearrangement of the wires on either side of the main. One of the advantages claimed for the American system is doubtless that there is little, if any, subsequent opening of main cable joints, but as regards the provision of branch cables it is a matter of some difficulty to estimate accurately where new branches will be required, and it is not by any means certain that main cables will not have to be opened again to provide additional branch cables in new positions. Our main cables are not opened unless the conditions are abnormal, and unless it is desirable to do so during an emergency period. The second advantage is that the provision of the 900-pair cable is deferred for a number of years. Is it correct to assume that the stub pairs are teed? The telephone public is critical as regards the recurrence of faults, and demands a service practically free from faults. For this reason it seems that in a system where the pairs are teed the susceptibility to faults is probably 100 per cent greater than in the British method. We should probably design our cable system and develop a district on the basis of building up branch cables and conduits for 15 years and main cables for 10 years, providing larger mains at the outset, deferring some branches, but providing a flexible arrangement with the minimum liability to faults. If the estimated development is approximately correct the main cables will not need to be opened over a long period, and although the initial cost may probably exceed that of the teed system (a point which is open to verification on a cost basis) the investment is sound and capable of a sure return. It is a matter of surprise to find that American engineers make such a liberal use of concrete. Our ducts are very rarely damaged. Some years ago in this district multiple-way ducts were damaged in one section through heavy traffic, but in this case the paving had not been permanently restored. Moreover, in laying earthenware conduits through large towns and cities it happens that in probably 90 per cent of the cases the conduits have necessarily to be laid at a greater depth than the standard 24 inches in the carriage-way, owing to the presence of foreign mains and obstructions, and this is an additional protection. I should be glad if the author would amplify his description of a cable paster on page 102. It would seem to be a wise precaution to pressure-test main cables after the completion of the plumbing operations, as it would be difficult to ensure that there shall be a perfectly hermetically sealed lead tube, say from Birmingham to Liverpool, by relying on the plumbers' work alone. Moreover, the cost of pressure-testing by either dried air or CO_2 is small as compared with the cost of renewing a length of expensive main cable. We use the air compressor on subscribers' cables, and the petrol desiccator on long-distance cables, and thus avoid the risk of replacements. Is it the author's experience that waxing the ends is sufficient to ensure a very high insulation resistance without desiccating? We use the desiccator as the construction work proceeds, and on completion of the cable we have a perfectly sealed tube, all leading-in points having been eliminated, and we can, if we desire, obtain an insulation resistance of 50 000 megohms per mile. Subsequent to the initial desiccating operations there is no further need to desiccate unless a fault occurs. If a fault occurs and moisture enters the cable, we first locate the fault and ascertain the cause. Subsequently the application of the desiccator will restore the insulation resistance to standard. To renew the length would probably necessitate rebalancing over a long distance—perhaps half a mile—a very expensive operation.

Mr. J. A. Morton: In the first part of the paper some of the reasons are given for the great development in the telephone industry in the United States. I think a further reason is that, generally speaking, the construction there is not so substantial as it is in the British Isles. Probably, however, the Americans are willing to take more risks and to experiment more frequently. They thus get a cheaper construction and a cheaper service. We are always hearing about the over-organization of the Post Office, but it is obvious from the remarks in the paper that the A.T. & T. Co. is very highly organized, though probably there is more local de-centralization than there is in this country, due to the fact that it is a much larger country than ours. I notice that the Americans put a percentage of tin or antimony into the sheath of both aerial and underground cables to strengthen lead. A lead sheath containing 3 per cent of tin is 50 per

cent stronger than a pure lead sheath, and as telephone cables are mostly air and loose paper inside, they have not much lateral strength. I think that for this reason the Americans are quite right in using tin both for underground and for overhead cables. I do not think the Post Office use any tin in their underground lead sheaths. We have used tin in the sheath of telephone cables laid direct in the ground and have omitted any armouring, merely giving the lead an overall serving of compounded tapes. This was for telephone cables laid close to power cables, and under the same cover board. I expect that the poles mentioned in the paper are untreated cedar poles, which are said to give a life of 19 years. I was under the impression that an untreated pole would last only from 14 to 17 years, though with creosoting under pressure that life may easily be doubled. There seems to be no general rule in America as regards the factor of safety of the poles. Some of the American companies replace the pole when the strength has decreased to 25 per cent of its original value, and sometimes they replace the pole, as mentioned on page 97, when the diameter has been reduced to 70 per cent of the original. A factor of safety of 4·7 is mentioned. If a large number of open wires are carried, do American engineers allow for $1\frac{1}{2}$ inches of ice on each wire and for a wind pressure of 7 lb. per square foot of the projected area of each ice-covered wire, as mentioned on page 97 in connection with aerial cable? In Great Britain no allowance is made for ice, but an allowance of 17 lb. per square foot (which is equal to 10·2 lb. per square foot of projected area) is made for wind; the poles having a factor of safety of 8 under such conditions. I should like to know what is the American practice with such open telephone wires. I notice that pole roofs are not used. Their cost is only small, but I am sure they would add to the life of the pole. In connection with the patent stay rods shown in Fig. 4, I should like to point out that soil reasonably free from large stones is necessary, otherwise they cannot be inserted. I doubt if they are as strong as a "dead man" when they are in position. The Americans use qualities of steel suspension strand with a very high tensile strength; that of one size goes up to 75 tons per square inch. It is very difficult to make-off stiff strand like this, and I suppose that is why mechanical clamps are used. There is not, however, much gain when the tensile strength of this steel strand is raised, because the elastic limit falls. For instance, a 45-ton quality of strand has an elastic limit of about 70 per cent of the breaking stress, say $31\frac{1}{2}$ tons per square inch, while a 60-ton quality has an elastic limit more nearly 50 per cent of its breaking stress, say 30 tons per square inch. The reason for using wooden insulator pins may be initial cheapness, but I think they will not last nearly so long as galvanized-steel pins. One point in their favour is that they will not rattle in the insulator. A lapping of jute string at the bottom of the threads on iron pins would stop jarring. I am surprised that glass insulators have been found so successful, as I thought that glass developed internal disruptive stresses under temperature changes and was very unreliable. In America clamps are always used for making-off the steel messenger wires, but I should like to know what is put on the ground ends of stay wires when making off. The British Post Office make-off very neatly without clamps. There are no projections left, and it does not take long to make the loop. I am not in favour of the single cable rings shown in Fig. 10. They certainly grip the wire and will not move about in a wind, but the support seems to me too small, especially when the cable weighs 4 to 8 lb. per foot. I prefer our chrome-leather suspenders, which provide some seating for the cable. Instead of the grade clamps shown in Fig. 12 we use a flat spring clip on each suspender on grades, which holds the chrome-leather strap tight to the lead of the cable. This distributes the pull over all the suspenders on a grade and is more effective in preventing the lead sheath from stretching than one grade clamp per span, in which case the pull is concentrated. With regard to the bonding on page 96, I do not understand why the continuity of the lead sheath should be broken when the cable goes from overhead to underground. Why should not the underground portion of the lead be earthed, like the overhead portion, which I assume is connected to the suspension wire, the latter being earthed at intervals? On the next page it is mentioned that there is a saving on the annual cost of aerial cable. If this means a saving in maintenance costs, I cannot agree; nor do I understand why it is stated that underground cable is more liable to total breakdown due to floods than is aerial cable. One would think that defects in the plumbing are more likely to occur in aerial joints made overhead than in joints made on underground cables. I do not like the idea of creosoted wooden duct, as this absorbs moisture and it is essential that the creosote oil be absolutely neutral or the lead may deteriorate. I should like to know the gauge of the wire used for drop wiring, and also whether it is of phosphor bronze.

Mr. W. Cowburn: I think that the methods of construction adopted in this country will bear favourable comparison with those in the United States. Our overhead routes certainly have a better appearance than those on the slides shown by the author. We are not in a position to adopt some of the quick methods of construction which are in operation in America, probably due to the fact that we have not the wild expansive territory to deal with, and to the varying conditions in the two countries. Owing to the State monopoly of the public telephone in this country, we cannot get the commercial drive which has resulted in such a huge adoption of telephones in the United States, where the industry has been left open to competitive commercial enterprise. On the other hand, we should have the advantages accruing from one ownership. In the staff organization shown in Fig. 1, there appears to be no Engineer-in-Chief, which means that the ultimate decision as regards technical matters rests with an individual who is not necessarily an engineer. Generally speaking, the staff organization appears to be similar to that in operation in this country, except that traffic is a separate division and not controlled by the commercial side. I should like

to know the specific duties performed by the Traffic Engineer and the Division Superintendent Engineers. Similar development studies to those given in the paper are adopted in this country, except that they are not in such detail. On page 88, col. 2, it is stated that the question of the actual type of plant to be adopted is always considered from the standpoint of economy, but, in addition, "the quality of service to be provided and the desire to set up conditions satisfactory to the public are important considerations." There is only one class of service in this country and that is the best we can give. Also, it is stated that in cost studies both the first costs and the annual costs are included "for a period over which unequal facilities exist." It is not clear to me what is meant by the two quotations which I have given. I notice that the use of $3\frac{1}{2}$ lb. conductors is being considered. British telephone engineers thought they had reached the limit with $6\frac{1}{2}$ lb. conductors, and when it is remembered that the conductor resistance of 1 mile of $3\frac{1}{4}$ lb. conductor will be approximately 550 ohms, and that, generally, the maximum resistance of subscribers' lines in this country is 300 ohms, it would appear that the scope for the use of a $3\frac{1}{4}$ lb. conductor in this country will be very limited. Will the author say what line-resistance limit is adopted for exchange lines in the United States. Owing to the different conditions in this country, I fear that aerial cable will never be used so extensively here as in America. It is thought much more likely that cheaper methods of construction will be looked for on the lines of protected cable. I should be glad to know if it is the practice in America to erect aerial cables on the same side of the pole throughout the entire length of the route, and whether, when negotiating a bend in the pole line, the cable is taken on the inside of the angle. My experience has been that where any metal comes into contact with the lead sheath, damage is done to an aerial cable, and had not the author pointed out the extensive use to which the "Bonita" and "Blackburn" suspension rings are used in the United States, I should have hesitated to use them. Perhaps he will explain why crystallization of the lead sheath is not set up at the point of contact, between the cable sheath and the rings, due to vibration transmitted from the suspending wire. What is the life and cost of fibre ducts, and why are they not satisfactory? Has creeping been noticed in underground cables, due to heavy road traffic? If so, to what extent, and what steps are taken to prevent it? Are all kinds of faults dealt with by the same men, that is to say, does one man clear faults on external lines as well as on internal apparatus (subscribers')?

Mr. W. Holttum: I think the most noticeable feature of this paper is that the installations described are on a very much greater scale than they are in this country, and the methods described are therefore only partially comparable with ours. The American practice in regard to cable insulation-resistance and desiccating is very interesting. It is very natural for us to criticize it in view of our own much more stringent methods, and particularly when such long lengths of their lines are in inaccessible country, so that certainty of service would appear to be more necessary than in our own case. We must not, however, overlook the point that their system is found to work well. I suggest that this may be accounted for by the fact that small faults do really exist where air pressure-testing is not carried out, but the amount of moisture admitted is insufficient to lower the insulation below the specified 500 megohms. Mr. Pratt referred to the British figure for insulation as 50 000 megohms, but to the best of my knowledge the insulation required on our trunk lines is 10 000 megohms. In any case this is far above the American standard, and would appear to be unnecessary for satisfactory transmission. It is mentioned on page 97 that the upkeep expenses of aerial cables are less than in the case of underground cables. Can the author give the reason, as it seems contrary to what one would expect? It is not apparent why the crank-handle method of jointing should not be adopted in this country. The third operation illustrated in Fig. 24, showing two wires with the paper stripped off ready for jointing, does not illustrate our usual practice, viz. to give the wires three or four half-twists before stripping off the paper, and it would appear to be a more convenient method.

Mr. R. C. Brookes: In Section V porcelain insulators are mentioned as having been superseded by glass insulators, as this material is most suited to American conditions. I should be interested to know any condition peculiar to that country which should decide this change.

Mr. F. Mercer: One feature which tends to distinguish American practice from British practice is the dependence of the former on the skill of the workmen, which appears to be such that faults attributable to bad workmanship are so few and unimportant that it is not worth while to take steps for their elimination. This is particularly noticeable in regard to the pressure-testing of cables. The British Post Office insist on a pressure-test of 20 lb. per square inch for 72 hours, and even the smallest leak which shows up during that time must be located and sealed up. Such a precaution ensures that there are no pin-holes or minor faults in the cable or joint wipes which could admit moisture, and also that any weak point or incipient fault in the lead sheath is discovered and remedied before the cable is put into commission. In American practice, however, it appears that pressure-testing is not carried out, presumably because the expense is too great, and it is preferred instead to risk occasional faults in the lead sheath, which faults may be responsible for admitting moisture, and which will in turn either create a definite fault or cause electrical unbalance between the wires of a 4-wire core, and therefore cross-talk between the three circuits in that core. I understand that one of the main objects of the British Post Office in insisting on a high value of insulation resistance is to eliminate any cross-talk attributable to low insulation, and I should be glad if the author would state if to his knowledge the balancing of long trunk cables in the United States has attained the same high standard as has been obtained by the British Post Office, because, if so, it will throw a new light on this question. I notice that the question of pressure-testing long-distance

cables in America is now being considered, and it will be interesting to know the result. One can but admire the flexibility and vision evidenced in the American system. It is only necessary to refer to the cable racking of large manholes, whereby any cable joint in the manhole can be readily made or altered without interfering with other cables; to balloon joints in a cable, whereby additional circuits can be loaded without undue difficulty; to stub cables by which a flexible distribution is ensured, and to the use of aerial cable with terminals on the carrying poles, whereby new subscribers can be readily connected, in order to see the high standard which has been obtained in this respect.

Mr. H. Adams: Referring to stub cables on page 89, the author says: "In practice the same numbers are brought out at two or more points." In this case what scheme is adopted to tell at which point these pairs are used? I am presuming this stub-cable arrangement to be similar to the **T** arrangement used by the Post Office, in which case the higher-numbered pairs are used, say, at the farthest point from the exchange. Records, of course, are kept in the test room. I agree with the author that the stub-cable method appears to be satisfactory for increasing the flexibility of the underground system, but what precautions are taken to prevent faults developing in the stubs? Can the author give details as to the construction of the concrete belt around the pole at the ground line mentioned on page 90? Are precautions taken to ensure that water does not lodge at the ground line of the pole? I notice that it is not considered necessary to provide earth wires as a protection against lightning. Is not the use of an earth wire primarily to prevent current leaking from wire to wire via the insulators and arms, and secondly to provide a lightning conductor? Is any trouble, e.g. the ringing of bells or cross-talk, noticeable due to the absence of earth wiring? One case came to my notice in which approximately 10 pairs of wires ran on the same route for 2 to 3 miles, and a private subscriber's telephone (an earth-circuit line running on the same poles) was regularly reported as being in contact with some other line. The subscriber's bell was constantly ringing, but not very loudly, and no voice could be heard on the line. Tests were made and wiremen sent to localize the trouble, but nothing was found. As this continued for some months, a thorough investigation was made, when the trouble was found to be due to the corrosion of the earth wires on practically all the poles just above the ground line. It was then discovered that the private subscriber's bell was rung whenever a subscriber at a distant automatic exchange called up a subscriber over this route. Now the difference (which I grant is substantial) in this case from the practice employed by the Americans, is that the leakage paths are practically metallic, whereas in the United States there is no earth wiring on the poles, and the insulation bolts are made of wood. Are glass insulators used solely because insect growth does not take place so rapidly in them as in opaque ones? Has the author any figures giving the insulation resistance of porcelain and glass insulators of the same type (1) in dry weather, and (2) in wet weather? I was particularly impressed by the methods employed for superimposing lines on aerial lines. I have spent much time in balancing lines to prevent overhearing on the superimposed circuits, which were called "plus" trunks. Sectional tests were made in order to localize the trouble to some particular section, but no one defect that would cause the trouble could be found. The trunks in question were about 30 miles long and included underground and aerial cables, and open line. The only conclusion we could arrive at was that the insulation resistance and capacity of the open lines, which passed through trees, were greatly and unevenly affected by the ever-changing atmospheric conditions. These "plus" circuits never worked satisfactorily, and I should be pleased if the author would say what he considers to be the explanation and how the difficulty is overcome in the United States. Are the American methods of renewing aerial cables similar to Post Office practice? Has the author had any experience of drop

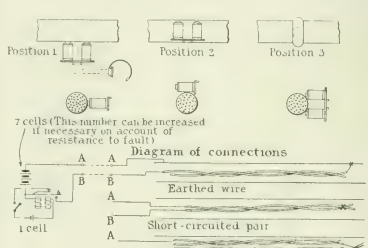

FIG. D.—Method of locating trouble, using exploring coil.

For earthed faults: Position 3 will generally give the loudest noise. If cable sheath or strand is earthed, position 3 will generally give noise beyond fault, so that difficulty may be experienced in locating the trouble. In such cases positions 1 and 2 will give noise between interruptor and fault, but silence beyond. For crosses and short-circuits, the coil should be held in position 1, and the spiral lay of the wire followed by means of the tone while moving the coil along.

Connection of interruptor as shown above should be made at cable box apparently nearest to the trouble, in order to reduce resistance to fault. In case of wet cable or where several pairs are earthed at one point, bunch as many faulty pairs together at "B" as convenient.

or vertical joints on aerial cables? These consist of a closed lead sleeve with an externally threaded brass collar, which is fitted to an internally threaded brass collar. The screwed joint is made damp-proof by the use of a rubber ring or washer. The two ends of the cable to be jointed are brought into the top of the collar, and the space between the cables and collar is securely closed by a wiped joint. The great advantage claimed for this joint over the horizontal type, is that conductors are more accessible for changes or tests. The moisture-proof qualities of the joint are claimed by Kemster B. Miller to be perfect, but I consider the mechanical construction to be very weak as the expansion and contraction of the cable will affect the wiped joint. I notice that in America **Y** joints are filled in with paraffin wax, and also that no cables are desiccated. What is the author's opinion of this system as compared with the British Post Office practice? I have known

cases where the crank-handle method of twisting has been employed, but continuity has been impaired on account of looseness of the joints. Are many troubles due to this cause experienced in the United States? I understand that in America all faults (with the exception of open-circuits) are located by the exploring-coil method, this instrument being often used by electrical contractors and gas engineers to locate concealed tubing, etc. It consists essentially of a buzzer and an exploring coil. The buzzer circuit is placed on one of the conductors (say one which is earthing and in contact with the sheath of the cable), while the other leg of the buzzer circuit is secured to the sheath of the cable. Fig. D illustrates the set and the method to be adopted to locate trouble. The manufacturers claim that the set will locate all cable troubles except open-circuits, and that, owing to the low voltage used, there is no appreciable interference with other circuits in the same cable. Another claim is that by proper manipulation of the exploring coil all return currents in the sheath of the cable tending to affect the easy location of the fault are effectively neutralized. High-resistance wet spots can be located equally as well as dead short-circuits. These two tests are the extremes of the requirements for a fault-finding instrument. The method of testing is to ascertain the approximate location of the fault by the Murray or Varley loop test and then to determine it definitely by the exploring-coil method. I have carried out many cable tests using the Varley loop method, but this to be accurate has to be very carefully done and good cable records are essential. I have also made experimental tests with a buzzer and an exploring coil and, so far as aerial cables are concerned, I have found no real difficulties. Underground cable-testing by this method is quite a different proposition, as the iron conduit around the cable appears to act as a magnetic screen, and I found it impossible to hear the tone when I was a short distance from the test-point (i.e. where the buzzer was located). To overcome this trouble I tried bonding the conduit to the cable sheathing so as to ensure good electrical contact, but I could get no reliable result. Can the author say if it is possible to locate troubles on cables in iron conduits by this method?

[The author's reply to this discussion will be published later.]

THE "CYC-ARC" PROCESS OF AUTOMATIC ELECTRIC WELDING.

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Summary.

From the earliest times, workmen have had to deal with the problem of fixing something to something else. This is a relatively easy matter with some materials, but becomes more difficult when dealing with metals. Since Elihu Thomson introduced resistance welding many years ago great developments have taken place in electric welding, but the problem of welding electrically by direct means two pieces of metal of widely different sections has hitherto remained unsolved, and the welding of dissimilar metals of widely different melting points, such as brass and steel, has been considered to be impossible. The "Cyc-Arc" process of automatic electric welding has, however, solved these problems, and it is believed that this system of electric welding stands unique, on account of the fact that by its means masses of metal, differing both in size and in quality, can be automatically welded together, as the result of a single operation of an ordinary bell-push, by the consequent heating of only the metal parts to be welded, without using or reinforcing in any manner with metal from any other source such as a metallic electrode or by the use of any flux.

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(8) Special machines for supplying power for direct-current welding.
(9) Considerations for the use of alternating current for the "Cyc-Arc" process of electric welding.
(10) Conclusion.

(1) Evolution and Development.

The "Cyc-Arc" process has been developed primarily in connection with ship construction, which is now known to be a relatively minor application for this system of welding, and which has possibilities for use throughout engineering constructional work generally, far beyond the application on account of which experiments were first undertaken. The process, to which attention was specially paid during the war on account of the dearth of suitable labour, is that of attaching small screws or studs to ships' plates to carry the supporting clips of electric cables and other fittings.

The advantages of a process of welding which will rapidly and satisfactorily attach suitable studs without any perforation of the bulkheads or decks, are obvious, and the process which forms the subject of this paper is the only known successful method of doing so.

The first attempt at any form of electric stud-welding for cable clips with which either of the authors wa associated, was made in 1917, by using the metall arc process with quasi-arc electrodes to deposit a rin of molten metal round the base of the steel stud i contact with the plate, thereby welding the stud t the plate. These experiments showed that great ski was required, on account of the small size of the stud in order to avoid excessive burning away of the latte while at the same time effectively melting and pen trating the relatively heavy plate; and the difficulti were such as to make it appear advisable to use bol or set-screws instead of studs, the heads of which wer welded to the plates. Though better results wer thereby obtained, special cable clips were necessar on account of the thickness of the bolt heads, and th welds were so unsatisfactory as regards both reliabilit and appearance, though largely on account of the clas of labour which was available, that this system of stu welding was never brought into regular use.

It is of interest to note that although at first th studs were retained in position for welding by mean of tongs, or their equivalent, held by one operato while the welding was carried out by another individua early in 1918 a light magnetic stud-holder was designe and constructed, by means of which the stud wa retained accurately in position upon the iron or ste plate, thus eliminating one operator. Fig. 1 show such a magnetic stud-holder.

While the above-mentioned stud-welding experiment were being carried out at Portsmouth Dockyard, ir structions were received from the Admiralty tha apparatus should be made and tested in accordanc with certain proposals which had been submitted c what was named a "semi-automatic device for stu welding." This apparatus, which was intended pr marily for the welding of iron or steel studs or screw to iron or steel plating, consisted of a pair of pot magnet supporting, but insulated from, a stud holder attache to a plunger, the latter being movable against th pressure of a spring, and fitted at one end with a insulated striking knob.

It was proposed to operate this apparatus by con necting the stud holder, stud, and plate in circuit wit a switch and regulating resistance. The apparatus wa intended to be fixed in a suitable position for the stu to be welded upon a steel or iron plate by simply ener gizing the magnets. Then, with the spring holding th stud out of contact with the plate, the switch was t be closed, after which it was intended that the kno at the end of the plunger should be struck in such manner as to overcome the action of the spring, mo mentarily bringing the stud in contact with the plate and also closing the welding circuit. The stud, however

after momentarily touching the plate, would be released and at once forced out of contact by the action of the spring, thereby drawing an arc which would rapidly melt the stud end and the plate opposite to it. This arc was to be allowed to maintain for a sufficient time, as checked by means of a stop-watch, at the end of which time the molten stud was to be forced against the adjacent molten plate by again pressing the knob of the plunger, thereby welding the stud to the plate, the current flowing in the main circuit through the stud, weld and plate, being finally switched off by hand.

When testing apparatus made in accordance with it was found should be less than 1 second, though the originator of the apparatus anticipated that a much longer time would be required. It was soon realized, therefore, that this method and apparatus were quite impracticable for stud welding, though occasional welds were obtained of a quality which indicated possibilities of further development of the arc method.

In view of the difficulties in striking the arc by hand, as encountered and demonstrated during the course of our experiments, further proposals were received, it being suggested that the plunger and stud holder should be arranged to operate by the action of a solenoid,

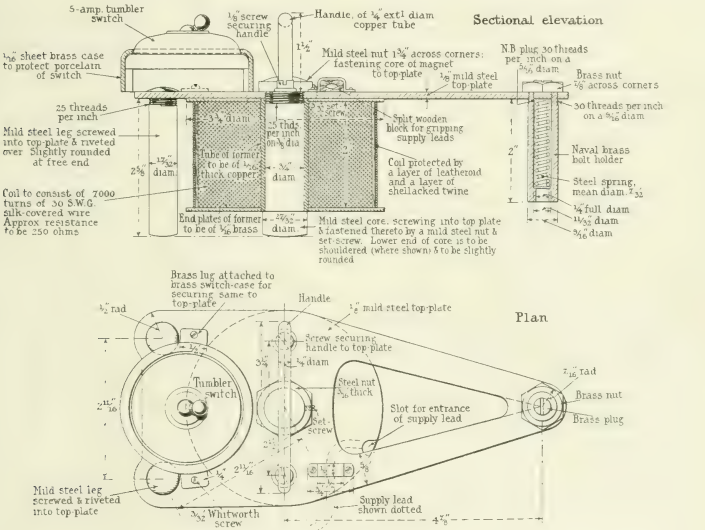

5-amp. tumbler switch
Handle, of ¾" extl diam copper tube
Sectional elevation
Mild steel nut 1¾" across corners: fastening core of magnet to top-plate
N.B plug 30 threads per inch on a 3/16 diam
Brass nut
30 threads per inch
Split wooden block for gripping supply leads
Coil protected by a layer of leatheroid and a layer of shellacked twine
Naval brass bolt holder
Steel spring, mean diam. 7/32
Mild steel leg screwed into top-plate & riveted over. Slightly rounded at free end
Coil to consist of 7000 turns of 30 S.W.G. silk-covered wire. Approx resistance to be 250 ohms
End plates of former to be of 1/16 brass
Mild steel core, screwing into top plate & fastened thereto by a mild steel nut & set-screw. Lower end of core is to be shouldered (where shown) & to be slightly rounded
Brass lug attached to brass switch-case for securing same to top-plate
Handle
Plan
Screw securing handle to top-plate
Tumbler switch
Steel nut
Slot for entrance of supply lead
Brass nut
Brass plug
Mild steel leg screwed & riveted into top-plate
Supply lead shown dotted
Whitworth screw

FIG. 1.—Magnetic stud holder.

these proposals, it was found that the chief defect was the difficulty in striking the arc, owing to the stud sticking to the plate immediately it was first brought into contact with the latter, due to the consequent heavy rush of current, even though endeavours were made to strike the end of the plunger in such a manner that the first contact should be too rapid to permit this sticking of the stud.

Although after practice it was found that arcs could sometimes be struck, the difficulty and uncertainty considerably increased another difficulty, viz. that of timing correctly, by means of a stop-watch and hand-operated apparatus, the arcing period, which the spring being altered so as normally to force the stud into contact with the plate. The solenoid was to consist of a few turns of heavy conductor connected in the main circuit in series with the stud holder and stud, and was to be adjustably mounted on, though insulated from, a pair of pot magnets similar to those used in the device previously described.

Apparatus was accordingly designed and constructed for trial. Early experiments with this apparatus showed quite clearly that the arc-striking difficulty had been surmounted, as would, of course, be expected with an apparatus designed in this respect to operate in exactly the same manner as an arc lamp, and these

early experiments appeared to indicate that a decidedly more satisfactory apparatus had been evolved for stud welding. The method of operation was as follows:—

After connecting up the operating solenoid, stud holder, stud, and plate in series with a suitable regulating resistance and supply mains, and after fixing the apparatus in the desired position upon a steel or iron plate by means of the hold-on magnets, the switch was closed for a short period which was checked by means of a stop-watch. At the end of this period it was opened and the apparatus removed, leaving the stud attached to the plate.

This attachment which, as the result of our earlier observations, appeared quite frequently to result in a satisfactory weld, was made by an arc being struck upon closing the switch, thereby energizing the stud-holder solenoid by means of the current which passed through it and also through the stud and plate. This arc melted the stud end and the adjacent plate and, upon opening the circuit, the solenoid was de-energized, thus allowing the spring to force the more or less melted stud into the probably considerably less melted plate, to which it became, in some cases, apparently firmly welded.

It is undoubtedly unfortunate that apparently good welds were obtained at this stage, for although, as will be explained, they were later proved to be, at the best, of very low mechanical strength, and therefore almost useless for any practical purpose, a great deal of delay was caused by endeavours to improve and obtain sound and satisfactory welding by the use of a method and apparatus which were later proved to be, in principle, essentially unsound.

The first apparently good welds were obtained by means of attaching studs to plates lying flat or horizontal which, speaking generally, is a favourable position for the simple reason that the molten metal from the stud tends to be deposited upon the plate beneath, and thus the crater of molten metal into which the stud is subsequently forced is increased.

On this account, inherent defects in the above-described method and apparatus were neither so apparent nor yet so serious as when welding was carried out upon vertical surfaces. In addition, however, in the early experiments there was a natural tendency to estimate results by means of rather superficial tests which, though they would perhaps at first sight appear satisfactory, were certainly not so. For instance, when using the above method and apparatus upon flat horizontal surfaces, welds could be obtained which appeared satisfactory upon external inspection, and which would withstand the stud being bent or hammered over even to the point of fracture, but which, upon examination at a later date in cross-section, in some cases had large blow-holes at their centres surrounded by narrow bands of welded metal, and, in other cases, showed that adhesion depended merely upon the sealing-in of the screw threads of the stud by the molten metal into which it had been replaced. It was, therefore, soon realized that even the best welds that could be obtained with the improved apparatus were not as good as they had at first appeared. In addition, it was also found to be impossible to obtain any approach to uniformity, even in the poor quality of welds obtained.

Although occasionally, after careful experiments had been made to try to ascertain the correct current, time and length of arc upon striking, a few apparently good welds would be secured, an attempt to repeat such welds under apparently identical conditions would generally result in failure. For this reason, two official trials of the apparatus in question were failures, though every care was taken to obtain satisfactory results. Each trial, however, indicated that there were possibilities, and we were thus encouraged to experiment further.

It appears desirable at this stage of the paper to call attention to the fact that though the apparatus, a portion of which has just been described, was, as already stated, proposed for use in the welding of small iron or steel studs, we found, as the result of numerous experiments at a comparatively early stage, that much better results could be obtained in the welding of brass studs to iron or steel plates. Not only were better welds produced, but the necessary adjustments for current, timing, etc., appeared to be less close, and in consequence, attempts at welding iron and steel studs were, at this stage of development, practically abandoned, in favour of first of all accomplishing what appeared to be an easier task, viz. that of welding brass studs upon steel plates or bulkheads.

Attention has been drawn above to the three variables which it was found had to be correctly adjusted in order to obtain even apparently satisfactory welds, viz. the amount of current through the arc, the length of the arc upon striking, and the length of time it had to be maintained before making the weld. Obviously, one or more of these factors must vary for every different size, shape, and material of stud, and, in view of the extremely short time during which it was found necessary to maintain the arc, it is not surprising that prolonged experiments with hand-timing against a stop-watch led to great confusion in results, and consequently delayed improvement. It was also found that considerable accuracy in all the above three factors was necessary to secure even moderately good results, this being a great obstacle in evolving a practical process and apparatus.

After the second unsatisfactory trial, special mechanical testing apparatus was arranged to make tensile tests of the stud welds in position, and this fully confirmed the unreliability of the welds, and also proved that the best of the apparently good welds had a tensile strength of less than half that of the stud itself.

After a series of experiments extending over many months, the difficulties experienced appeared to be almost insuperable, until a careful analysis was made of the various factors which were likely to be adversely affecting the operation of the system, and producing welds which were unsatisfactory as regards uniformity, reliability and mechanical strength.

The factors which received our closest consideration were:—

(A) The accurate timing of the sequence of operations.
(B) The influence of the shape of the stud end in preventing the decentralization of the arc.

(C) The length of the arc upon striking, and the accurate adjustment thereof.

(D) The apparent chilling of the molten metal during the period of replacement of the stud on the plate after switching off the current.

With regard to (A), the welding current, as explained above, was originally intended to be controlled by means of a knife switch, which we, however, replaced shortly afterwards by a remote-control contactor. In either case, the time of duration of the arc was determined by means of a stop-watch, the switching operation being performed by hand. The required duration of the arc for the size of stud which we were trying to weld is well under 1 second, and it was surmised that, in order to obtain uniform results, more accurate timing than could be obtained by the above-mentioned method was essential. It was, therefore, decided to experiment with an automatic timing and control system, the final design of which is fully described later in the paper, and which, in practice, was found to yield important improvements in the direction of obtaining uniformity in the resulting welds.

With regard to (B), all the earlier experiments with small studs, referred to above, were carried out with studs having plain square ends, or cone-shaped ends terminating in a fine point. The former yielded, if anything, slightly better results than the latter. The majority of the welds obtained with both types were, however, defective, largely owing to the fact that the arc became decentralized relatively to the axis of the stud. This effect was at first attributed to the magnetic influence of the holding-on magnets and operating solenoid, as it was found that, by making the magnetic polarity of all three solenoids alike, a somewhat more stable arc was obtained.

The decentralization of the arc, apart from the above cause, was considered also to be due to its natural tendency to wander to one side, particularly when assisted by other influences such as currents of air, explosive effects due to the arc itself, and also movement of the molten metal. Effects such as that due to currents of air could be overcome by suitable shielding and other means, but that due to the gravitational movement of the molten metal, which was encountered when welding on to a vertical surface, offered much greater difficulties. It was decided to experiment with a special form of stud end with a view to overcoming the last-named difficulty.

When approaching this problem we had in mind, not only the necessity of centralizing the arc as much as possible throughout the entire period of operation, but also the desirability of forming an enlarged crater of molten metal in the plate into which the stud end is to be inserted. These two objects have been achieved by the use of the stud end illustrated in Fig. 2.

Referring to (C), we readily appreciated that uniform results with the "Cyc-Arc" process could not possibly be expected unless the length of arc upon striking was not only uniform, but also accurate, in accordance with the length determined from numerous experiments as being the one producing the best possible welding results. The length in question is simply that which has been found just sufficient to enable the arc to be uniformly and reliably struck and maintained. With the apparatus already described, two methods of regulating the length of arc upon striking had been used, neither of them giving, however, completely satisfactory results. With the first method, a sheet-metal gauge or distance-piece $\frac{1}{16}$ inch thick (this having been found to be the best arc-length upon striking) was inserted between the stud and plate when making the preparatory adjustments at the welding tool previous to effecting each weld, the solenoid of the tool being then forced towards the plate by means of the adjusting screws and nuts attached to the hold-on magnets, until it came up against the shoulder of the insulating sleeve surrounding the solenoid core. By withdrawing the distance-piece from between the stud and plate, the former was pressed into contact with the latter by means of the spring, and was then in position for an arc to be struck of a length equal to the thickness of the distance-piece.

FIG. 2.—Ball-headed stud.

The second method of adjustment, which was more easily and more rapidly effected than the first, was, however, probably rather less accurate. In this method, before making each weld the position of the solenoid was so adjusted relative to the stud and plate, and with reference to the position of a mark made upon the square spindle which projected through the spring housing at the upper and outer end of the welding tool, that $\frac{1}{16}$ inch was provided as the striking distance of the arc.

As, however, neither of these methods provided a simple and comparatively fool-proof means of effecting the desired adjustment at the welding tool, the arrangement shown in Fig. 3 at 35, 36 and 38, was designed and constructed. The method of adjustment with this device is simply to screw down the adjusting head (35) until the plunger (36) just comes into contact with the solenoid core (31). As the plunger (36) projects beyond the adjusting head (38) by exactly $\frac{1}{16}$ inch, it will be seen that this will determine the exact length of arc which is struck when the solenoid is energized.

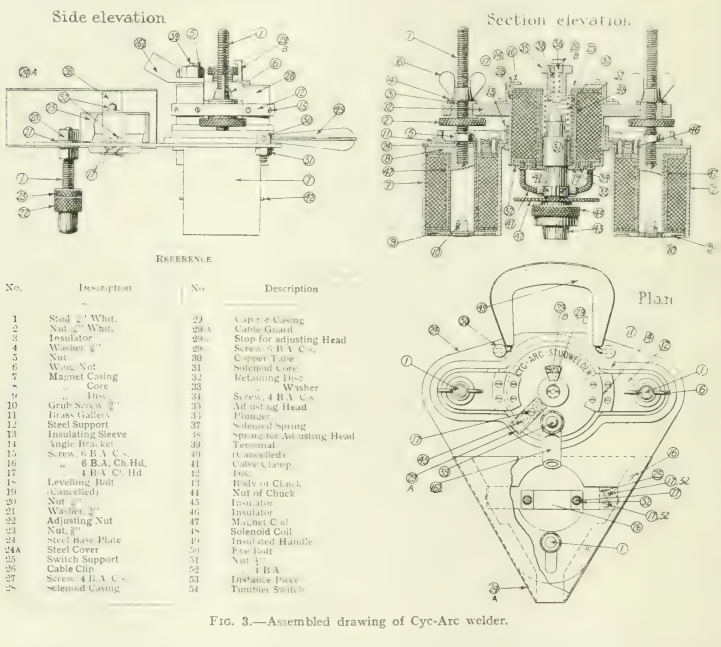
The provision of this device has no doubt greatly facilitated the obtaining of uniform and accurate adjustment of the arc length upon striking, this adjustment being very necessary for the satisfactory operation of the "Cyc-Arc" apparatus.

It is of interest to note also that a limiting device (29B, Fig. 3) has been fitted to the welding tool, this device indicating when it is necessary for the

position of the solenoid and accessories to be adjusted relative to the plate by means of the adjusting screws and nuts (1) and (6).

With regard to (D), the elimination of the troubles mentioned under (A) and (B) had resulted in fairly uniform and reliable welds being obtained with a mechanical strength equal to about half that of the studs themselves, but it was evident that a much greater mechanical strength was desirable, the ideal being for the weld to be as strong as the stud itself.

and weld more or less satisfactorily, but prevent the forcing home of the stud into the plate and the complete closing up at the centre of the weld. The stud is therefore welded around its periphery, but at the centre there is left a cavity, the extent of which is dependent upon the viscosity of the molten metal at the moment that the stud reaches the plate, and also upon the magnitude of the force causing the replacement. It is interesting to note that this "cavitation" effect was at one time thought to be inevitable, as a bubble,



REFERENCE

No.	Description	No.	Description
1	Stud 2" Whit.	29	Copper Casing
2	Nut 2" Whit.	29A	Cable Guard
3	Insulator	29B	Stop for adjusting Head
4	Washer 2"	29	Screw 6 B A C.S.
5	Nut	30	Copper Tube
6	Worm Nut	31	Solenoid Core
7	Magnet Casing	32	Retaining Disc
8	" Core	33	" Washer
9	" Disc	34	Screw 4 B A C.S.
10	Grub Screw 2"	35	Adjusting Head
11	Brass Gallery	36	Plunger
12	Steel Support	37	Solenoid Spring
13	Insulating Sleeve	38	Spanner for Adjusting Head
14	Angle Bracket	39	Terminal
15	Screw 6 B A C.S.	40	(Cancelled)
16	" 6 B.A. Ch. Hd.	41	Cable Clamp
17	" 4 B.A. C. Hd	42	Disc "
18	Levelling Bolt	43	Body of Chuck
19	(Cancelled)	44	Nut of Chuck
20	Nut 2"	45	Insulator
21	Washer 2"	46	Insulator
22	Adjusting Nut	47	Magnet Coil
23	Nut 2"	48	Solenoid Coil
24	Steel Base Plate	49	Insulated Handle
24A	Steel Cover	50	Fixe Bolt
25	Switch Support	51	Nut 1"
26	Cable Clip	52	" 4 B A
27	Screw 4 B.A. C.S.	53	Distance Piece
28	Solenoid Casing	54	Tumbler Switch

FIG. 3.—Assembled drawing of Cyc-Arc welder.

On carefully examining sections, it was generally found that blow-holes had been formed in the centres of the welds, the outer peripheries having, as a rule, the appearance of being satisfactorily welded. It was considered that this effect was caused by the chilling of the molten metal on the current being switched off prior to the replacement of the stud on the plate. This chilling naturally starts at the periphery, viz. the part farthest from the centre of the arc, with the result that upon replacement of the stud, owing to the "cratering" effect of the arc upon both stud and plate, the chilled peripheries meet first

presumably of nitrogen, appeared to be entrapped in the centre of the weld, but it has since been demonstrated that the formation of such a cavity can be prevented.

The reason for suggesting that nitrogen filled the hole at the centre of the weld is that, in the case of every weld which was completely sealed around its periphery, on cutting a section the metal forming the walls of the cavity showed no signs of oxidation, whereas, with welds in which the holes extended to the periphery, oxidation of the walls of the cavities was always in evidence.

As previously described, the sequence of operations giving the above-mentioned results included the following :—

(1) The closing of the main circuit in which the plate, stud, and the solenoid actuating the stud holder are connected in series, resulting in the striking of the arc as soon as the value of the main current in the solenoid rises to a sufficiently high value.

(2) After a sufficient time interval during which the arc is maintained, the main circuit is opened and the arc broken, the stud being afterwards thrust back on to the plate by means of the spring, as a result of the de-energizing of the series solenoid.

Although the return of the stud takes place in an extremely brief space of time after the arc is broken, this period which, of course, depends largely upon the design of the series solenoid and its consequent rate of de-magnetization, is by no means negligible, as compared with the high rates of heating and cooling of the metal at the weld, and undoubtedly accounts for the chilling referred to in (D) above.

After coming to this conclusion, partially hand-operated experiments were carried out with the following sequence of operations :—

(1) The striking of the arc by the series solenoid, as previously described.

(2) After a sufficient interval, the replacement of the stud through the path or direction of the arc with the current still maintained, by forcing back by hand the solenoid plunger and stud holder against the action of the solenoid, resulting in an actual rise in value of the current upon the replacement.

(3) The opening of the main circuit a short time after the replacement of the stud.

The results thus obtained were such as undoubtedly to indicate that this modified sequence of operations would result in much better welds, though some uncertainty arose owing to the hand-operation for replacement, again necessitating hand-timing.

Attempts were made to operate with this sequence by short-circuiting the series coil as the second operation, allowing the spring to act and replace the stud with the arc still maintained, but this was abandoned and has not been subsequently used, even with automatic timing, on account of the additional heavy short-circuiting switch and leads which are needed.

Owing largely to the persistence of one of the co-patentees, it was at this stage decided to modify the welding apparatus considerably, in order to enable it to operate in accordance with the last-mentioned sequence of operations, the duration of the arc being, however, automatically timed. To effect this, the series solenoid of the welding tool was replaced by a shunt solenoid, which was arranged to be operated and controlled from the automatic timing apparatus which had already been tested, but which also had to be modified in order to effect the energization and de-energization of the shunt solenoid, independently of the flow of the main welding current.

The first tests of the modified apparatus were, however, discouraging, on account of the difficulty encountered in striking the arc with the shunt solenoid.

It was anticipated that this would be effected satisfactorily by means of the adjustment at the timing apparatus of the relative times of closing the main welding-circuit contactor and the shunt solenoid of the welding tool, but the results were as follows :—

The closing of the main welding circuit before that of the shunt solenoid resulted in the fusing of the stud to the plate, thereby preventing the arc from being struck, owing to the excessive value of the current through the stud and plate when in contact, combined with the slow pull-off action of the shunt solenoid, caused by inductive effects. It was also found to be impossible to adjust the timing apparatus so as to avoid this trouble safely, without energizing the shunt solenoid actually so much in advance of the main circuit contactor coil that the solenoid tended to draw the stud away from the plate before the main circuit was closed, no arc thus being struck.

These difficulties were finally overcome by altering the connections of the whole apparatus so that the shunt solenoid should be energized as the result of closing the main circuit contactor, and by introducing reactance into the main circuit so as to delay the rapid rise in value of the main welding current, and permit the shunt solenoid to act and strike the arc without the stud sticking to the plate.

In consequence of these improvements, completely successful results, both in operation and in welding, were achieved, and substantially the same process and apparatus and method of connection have been used ever since. The welds thus obtained exceeded our best anticipation, both in quality and in uniformity.

It was in fact found, as the result of careful tests, that the strength of the weld actually exceeded that of the stud itself, and this is the standard which we have set ourselves to maintain ever since, in welding studs on to material as strong as, or stronger than, that of the stud itself.

The method of welding which has been described, and which has enabled us quite readily to make the remarkable welds described later, is summarized as follows in our Patent Specification No. 156 836 :—

" The method consists in the formation of an electric arc between the metal studs and the body into or on which the stud is to be welded, maintaining the said arc and current for a suitable length of time, the period of which is automatically controlled, and subsequently, but before interrupting the flow of the main current, forcing the molten stud end against the molten metal body by electrically or mechanically actuated means."

Although for a long time after success was obtained we believed this welding process to be entirely new, we have since found that the fundamental method was discovered and presumably used in about 1890, but with hand instead of automatic operation and control of the time-period of the arc. It is evident, therefore, that the application of automatic timing by means of electrical control is the principal feature of our invention, the lack of which feature prevented this effective welding process from being developed and utilized at least 20 years ago.

A detailed description of our timing and control apparatus is, therefore, now desirable.

The apparatus selected for experimental purposes

and with which the first successful results were obtained, was made by partially dismantling an ordinary Morse inker, an instrument well known to most electrical engineers. The portion used consisted merely of the spring-operated mechanism, mounted in its frame and controlled by an air speed-governor, and brake. It was found that the tape roller spindle of this apparatus made one complete revolution in about 4 seconds from starting, with an intermediate setting of the governor speed adjustment. It was decided, therefore, to fit brass cams upon the spindle in question, and mount insulated contacts upon the framework of the mechanism, which contacts would co-operate with the cams when rotated by the mechanism, to close and open circuits as necessary to secure the desired sequence of operations.

When first used for successful welding experiments, the apparatus was fitted with two such cams and their corresponding insulated contacts, one, called the main cam, being used for closing and opening the main contactor control circuit before and after each weld, and the other being used for short-circuiting the shunt solenoid for a short period during each welding operation, thereby effecting the completion of the weld after maintaining the arc for the required period.

The time period between the contacts made by the main and short-circuiting cams, which governs the period of the arc, was at first determined by the relative angular positions at which they were adjusted and fixed upon the cam spindle, but a simpler and better adjustment was provided at a very early stage by making the main cam involute in shape, and providing it with a spring-pressed slidably adjustable plunger contact, which varied the exact time of closing the main contactor circuit relative to the time of short-circuiting the shunt solenoid, according as it was brought up to, or away from, the involute cam. The short-circuiting cam was radial in outline, and covered about a quadrant of a circle in the early apparatus. It was preferred to short-circuit rather than open the shunt solenoid circuit by means of this cam, in order to improve the operation of the welding tool, to avoid sparking between the cam and its contact, and to prevent inductive pressure-rises at the coil itself.

This early timing apparatus was started and stopped by the hand operation of its brake lever, one complete revolution of the cam spindle being necessary to effect the sequence of operations for each weld. Though this method of controlling the movement of the timing apparatus was quite simple and effective, its chief defect in practice was that it necessitated the attendance of the operator at the timing apparatus during welding, the operator thus being compelled to leave the welding tool. Alternatively, two operators would be necessary.

Additions to, and modifications of, the apparatus, were therefore next made, by means of which the timing apparatus was started and stopped, and the whole sequence of operations required to make a weld effected by simply pressing an ordinary bell-push attached to the welding tool. This important improvement, though really of quite a simple nature, is best understood by reference to Figs. 4 and 5. Fig. 4 shows the connections and general arrangement of the controller, timing apparatus and the welding tool, with hand operation of the brake lever for starting and stopping the timing apparatus. Fig. 5 shows the additions and modifications made to obtain single-action push-button control at the welding tool.

It will be noted that the improvement is achieved by operating the brake lever of the timing apparatus by means of a small solenoid connected in series with an additional cam and contact finger fitted to the timing apparatus, across this cam and its contact finger being connected the push-button which is attached to the welding tool. This additional cam is circular in shape, but is provided with a small gap in its periphery, on account of which this cam is not in contact with its finger when the timing apparatus is inoperative, but when the push-button is pressed the timing apparatus brake-release solenoid is energized, and the apparatus therefore starts, almost immediately bringing the cam with a gap into touch with its contact finger, thereby maintaining the brake-release solenoid circuit

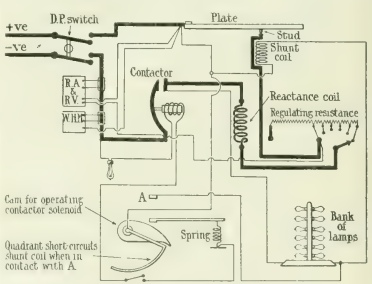


FIG. 4.—Diagram of connections, with hand operation of timing apparatus.

independently of the push-button, which can therefore be released. Hence, the timing apparatus continues to move until one complete revolution of the cam spindle has been made, when the gap in the cam causes the brake-release solenoid circuit to open. The apparatus, therefore, immediately stops, with the cam spindle in exactly the same position as that from which it started.

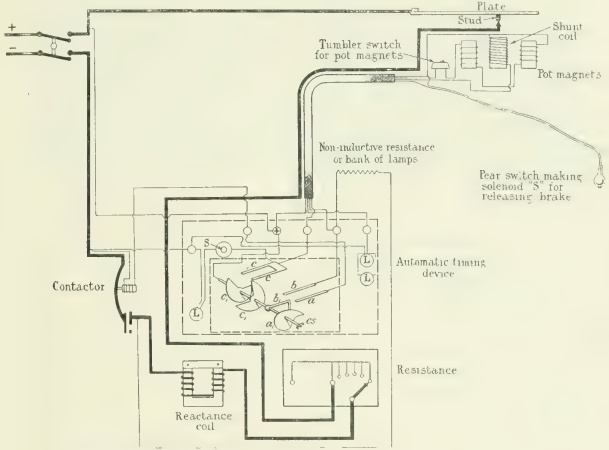
Almost immediately after the apparatus arrived at the stage which has just been described, an official Admiralty test of the process and apparatus was carried out on board a large warship for the purpose of ascertaining its usefulness and reliability for welding small brass studs to ships' bulkheads, for attaching the clips which retain in position the electric cables of all naval vessels. Extremely successful results were obtained at this trial, which was reported upon favourably by all the Departments concerned, and, in consequence, instructions were received for further tests and experiments to be carried out with the process and apparatus.

It should be noted that the majority of the studs

welded at the above trial were tested to destruction by means of screwing up a nut against a distance piece, with the result that in only one or two cases did the studs fail to fracture in the threaded portion rather than at the weld. This is still considered to be the most satisfactory method of testing such welded studs, and we think it will be agreed that it is a very severe and practical test which meets all requirements.

Reference has already been made to the difficulties in welding steel and iron studs, as compared with those made of naval brass, and at this stage of development, just after this trial, further experiments were made and the results carefully considered with a view to attached to the stud holder of the welding tool. Though a considerable period elapsed before it was possible to get an experimental apparatus of this type constructed, the results ultimately obtained with the first model apparatus of the type in question at once showed that our theories were correct, and that satisfactory welds of steel or iron to other metals could be obtained with it.

We have since classified the two kinds of welding apparatus as Type A and Type B, the former being essentially of a portable type, having a welding tool provided with hold-on magnets and spring replacement of the stud-holder plunger, the latter being of a fixed



S = solenoid for releasing brake on cam shaft (cs).
L = lamp resistance.
a = contact which, when connection is made with cam a_1, operates contactor solenoid.
b = contact which, when connection is made with quadrant b_1, short-circuits shunt coil.
c = contact which, in conjunction with split cam c_1, brings cam shaft (cs) into correct starting position.

FIG. 5.—Diagram of connections, with push-button control.

finding some method or apparatus which would satisfactorily weld such studs. It was decided, as the result of this investigation, that defective welds with these metals were obtained mainly on account of the faulty methods of returning the stud to the plate after the arc had been maintained. As already described, this was done by means of the action of a spring, following the de-energizing of the solenoid coil. We considered, however, that satisfactory welds of the type in question would only be secured by returning the stud to the plate under powerful and sustained pressure, and we therefore designed a tool which returned the stud to the plate under the action of compressed air admitted into a cylinder, the piston of which was or shop-tool type, the welding tool being attached to a slidable spindle, such as that of an ordinary post drill, and being connected to a compressed-air supply through an electrically operated valve, in order to replace the stud against the plate under air pressure.

(2) Automatic Timing and Control Apparatus.

Before proceeding to describe the two types of apparatus as they now stand, we consider it desirable to give particulars of our latest form of timing and control apparatus, which is common to both the above-mentioned types of apparatus, and which has been evolved on account of our realization of the importance of perfecting this portion of our welding

apparatus in order to secure reliable and satisfactory operation.

Though in principle it is the same as the early timing and control apparatus already mentioned, it embodies three main improvements, apart from its more robust and accurate and better finished mechanism, in that it is driven by means of a very powerful, double-spring motor, has a gravity-loaded vertical plunger contact for its main involute cam, and is provided with a uniformly divided and clearly marked timing dial and accessories, which can be simply and instantaneously adjusted to ensure that the apparatus will accurately maintain the arc for any period between 0·1 and 3·0 seconds, variations of 0·01 second being readily obtainable. As a model of this apparatus is available for inspection and operation, it is unnecessary to describe it in further detail, beyond explaining that the simple and accurate time adjustment is secured because the rotation of the marked dial causes the rotation of a spindle, to one end of which is attached a cam, which regulates and limits the lowest position of the main plunger contact of the apparatus relative to the main involute cam. The cam in question being of similar shape to the main involute cam, it will readily be understood that if the main plunger contact is normally allowed to drop to a low position, it will make contact with its own involute cam proportionately earlier than if retained normally in a higher position, thereby increasing the arcing period, for the reasons which have previously been explained. In its upper or zero position, although, as the result of the operation of the timing apparatus, the main contactor closes momentarily, the arc-striking solenoid is not energized, for the simple reason that the stud-holder solenoid is short-circuited at the moment the contactor control-coil circuit is closed.

This improved timing and control apparatus has so far quite justified itself in the results which have been obtained with it in conjunction with the rest of the "Cyc-Arc" apparatus. The period of each complete rotation of the cam spindle of this improved apparatus is 7 seconds, which is rather longer than that of the earlier apparatus, but is necessitated by the fact that the first half of the revolution, which occupies about 4 seconds, takes place before the cam spindle is running at full and uniform speed under the control of the powerful ball governor which is provided. With an accurate timing device such as has been described, it will be understood that it would be unsatisfactory to attempt to carry out any welding operations except as the result of the main and short-circuiting cams making contact in the latter half of each rotation of the cam spindle when it is revolving at a perfectly uniform speed. In cases, however, of the use of the "Cyc-Arc" apparatus continuously and rapidly on one particular class of job which requires a practically uniform time period, a much cheaper and simpler timing and control apparatus can be provided, so designed that instead of each operation of the timing apparatus occupying a 7-second period, the arc strikes practically instantaneously when the push-button is pressed, the total time period of this form of direct-acting timing device being practically the same as that of the arc.

About 400 welds can be made with the timing device without re-winding.

(3) Types of Apparatus.

The Type A portable "Cyc-Arc" apparatus, as now constructed commercially, consists of two main parts, viz. the Controller and the Welding Tool (see Fig. 6).

The controller is constructed with a strong angle-iron framework completely enclosed in sheet iron and expanded metal, and is divided into three compartments containing the following main items of apparatus:—

Compartment A.

(1) Automatic timing and control apparatus.
(2) Marble connecting and regulating panel.
(3) Adjustable reactance.
(4) Non-inductive resistance.
(5) Carbon-filament lamp resistance.

Compartment B.

Resistance coils for current regulation, with supports and insulators.

Compartment C.

Automatically-operated electric contactor.

Details of the most important item of the controller, i.e. the automatic timing and control apparatus, having already been given, it is unnecessary to refer to them again.

The marble regulating and connecting panel is fitted with a set of terminals connected to the ends of nichrome resistance coils, so that the latter may be arranged either in series or in parallel, or practically in any combination thereof, as the result of suitable linking up of the panel terminals. By this means large variations, both in the current-carrying capacity and in the ohmic resistance of the coils, can be obtained, thus permitting of a wide range of adjustment for welding purposes. The maximum current-carrying capacity which can be arranged by this means is much higher than can be dealt with by the usual contactor supplied with the apparatus, the rating of which is 500 amperes at 100 volts. One great advantage, however, of the design of the Type A controller, owing to this arrangement of the resistance and control panel is that, in case it is desired to supply a controller for much larger work, the only modifications necessary in the standard controller are the substitution of a contactor of greater capacity and an increase in the size of the main connecting leads. The latter leads consist of solid copper rod with bead insulation, whereas the control circuits consist of light flexible rubber-covered and braided wire.

The welding tool has already been fairly fully described. Certain improvements, as compared with the design described, have, however, been made, in order to suit practical working conditions. The controller and welding tool are connected by two cables, which are required for the two separate and distinct circuits of the apparatus mentioned above, i.e. the control circuit and the main welding circuit.

For the control circuit, between the controller and welding tool, a 4-core cab-tyre-sheathed cable is used,

which is permanently wired to the welding tool and is connected at the marble panel of the controller by means of a 4-pin plug fitting into corresponding sockets.

manently connected to the welding tool and is attached to the controller by means of a terminal stud provided on the marble panel.

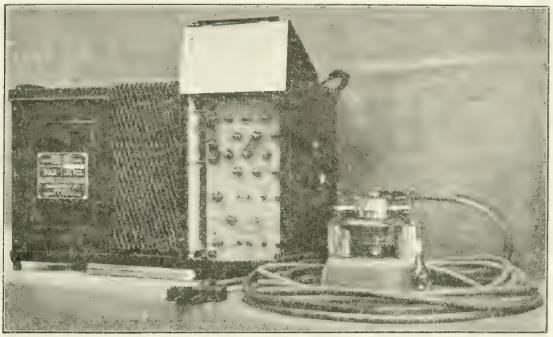
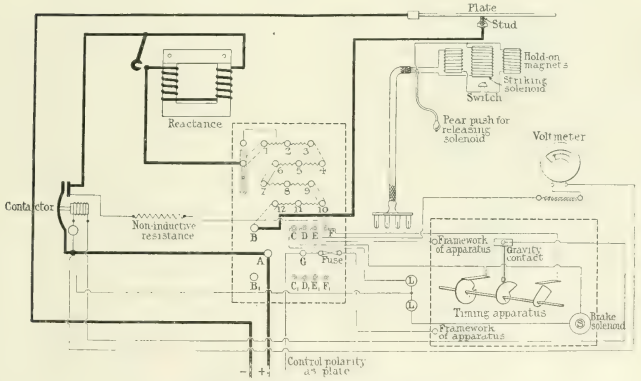


FIG. 6.—Complete Type A Cyc-Arc automatic welding apparatus.



A = main supply cable.
B, B_1 = terminals for cables carrying welding current to welders.
C, D, E, F / C_1, D_1, E_1, F_1 = sockets for 4-pin plugs.
G = terminal for control wire.
L = lamp resistance.
1–12 = terminals of regulation resistance.
S = brake solenoid.

FIG. 7.—Diagram of connections of Type A Cyc-Arc welding apparatus.

The main welding circuit between the two sections of the apparatus is connected by means of a single-core rubber-covered and braided cable, which is also per-

It will be noticed that provision is made in the standard Type A controller for the connection of two welding tools, if it is desired to use two such tools in

order to double the output of a single-controller set of apparatus. These two tools are operated on our dual-control system, to which further reference is made later in the paper. Fig. 7 shows the connections of the commercial Type A apparatus.

The following descriptive and instructional notes on the standard commercial Type A apparatus are of interest :—

The "Cyc-Arc" welding apparatus is designed for operation from ordinary direct-current welding supply mains, and only very slight modifications are necessary to make it suitable for any voltage between 60 and 100. The normal current-range is from 200 to 500 amperes, according to the size of the stud or other fitting to be welded. The actual energy consumed per weld, however, is extremely small, the usual duration of the welding current being about 1 second.

The apparatus will satisfactorily weld naval brass or manganese-bronze studs of good quality up to $\frac{1}{2}$ inch diameter on to brass, manganese-bronze, iron, or steel of practically any thickness, and also on to galvanized iron or steel.

Once the apparatus has been set up for a particular size of stud or fitting its operation is practically automatic, and it can be worked by semi-skilled labour.

The operations necessary for making a weld (after the controller and the surface on which the weld is being made have been connected to the supply mains) are as follows :—

The stud or other fitting to be welded is first placed in the holder of the welding tool, and the latter is secured in the desired position by means of the hold-on magnets.

The arc-limiting device is then set, after which a single action of the bell-push starts the timing and control apparatus, thereby making the welds. The cams of the timing and control apparatus stop automatically in exactly the same position relative to the contact fingers as that from which they started. The weld having been made, the tool is removed from the surface (to which it is attached by the magnets) by opening the tumbler switch and withdrawing the tool from the stud, which remains welded in position.

The portable "Cyc-Arc" apparatus (Type A) is so designed that the welding tool can be taken to any position where the work has to be performed, such as on the bulkheads or decks of ships. The entire equipment can be transported by two men, the welding tool itself being readily and conveniently handled by a single operator, its weight being under 20 lb.

To obtain the best results, it has been found advisable for a skilled artisan to make the requisite adjustments for current and timing to suit any given size and quality of stud, tube or other fitting, after which the apparatus can be handed over to semi-skilled labour to repeat welds in accordance with the first setting.

The value of the current required with a given time-setting is that which is just sufficient to raise the temperature of both stud and plate high enough for a satisfactory weld to be made. This value depends to a certain extent upon the time during which the arc current is maintained, and vice versa, but, as there is in metallic arc-welding always a certain current density which gives the best results, the time during which the arc is maintained has to be adjusted finally to suit the welding current used.

The length of arc, duration of current and length of time, and hence the resulting heat produced by the arc, should be kept at a minimum, providing that satisfactory welds result. There is, however, substantial range for adjustment, throughout which range no seriously deleterious effects on the welds need be anticipated. Too much heat, however, produced by excess of current, time or arc-length upon striking (any one of which will also result in an excessive final length of arc), produces porosity and burning of the metal adjacent to the weld, which will consequently be of relatively low mechanical strength.

The approximate range of arc-current adjustment is between 200 and 500 amperes, with a 100-volt supply. Though much larger currents can be provided for by suitable linking-up, they should not be used unless a contactor of greater capacity is substituted for that supplied with the apparatus, larger main leads being, in this case, also necessary.

The information supplied with the welding set respecting the current and timing adjustments is approximately accurate for welding on to plates from $\frac{1}{4}$ inch to $\frac{3}{8}$ inch thickness. For thicker plates, however, there must be a slight increase of current or time, or both, while for thin plates a corresponding reduction should be made.

If the apparatus is properly adjusted and the plates are clean, the only likely trouble is that due to currents of air (such as those in draughty passages) which may cause the welding arc to be blown to one side, if not actually extinguished. In such cases, steps must be taken to shield the stud welder from excessive draughts.

To ensure a sequence of good and uniform welds the mechanism of the timing device should be fully wound up once every day when stud-welding is in progress, by means of the winding key provided.

Care must always be taken that the stud welder is rigidly attached with the stud at right-angles to the plate. This will readily be effected by means of the adjustable back leg. For overhead welding, however, the welder can be correctly fixed and steadied by screwing back the cylinders covering the hold-on magnets, until they touch the plate.

In the event of the apparatus being used in a position where one hold-on magnet would be relatively higher than the other, such as a cross-lapped plate, an iron bolt is provided for insertion into the end of the iron core of one holding-on magnet, and should be adjusted until the magnets are at right-angles to the plates.

The hold-on magnets of the welding tool are provided with an adjustment to allow of the tool being readily adapted and fixed to uneven or curved surfaces.

It is also of interest to note that a fixed type of welding tool has recently been designed and constructed for use with the Type A apparatus, by simply adapting the essential operating solenoid with its supports and accessories to fit any kind of light post-drilling machine. This adaptation already promises to have a wide field

of application in engineering shops generally, for light work.

The Type B electro-pneumatic " Cyc-Arc " apparatus also consists of two main parts, i.e. the controller and the welding tool, but additional arrangements have to be provided for the supply of compressed air. It

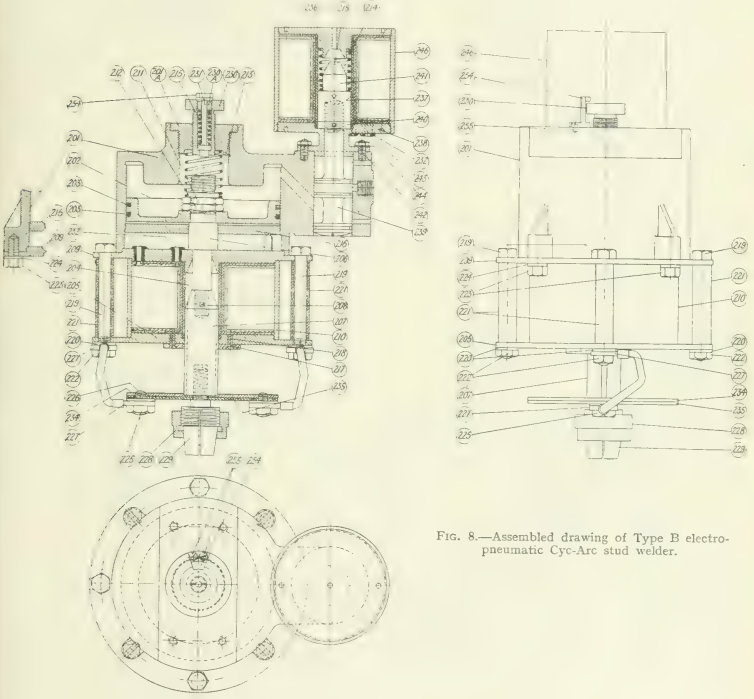


FIG. 8.—Assembled drawing of Type B electro-pneumatic Cyc-Arc stud welder.

is unnecessary to describe the controller, for the reason that it will consist of practically the same essential apparatus as that provided in the Type A controller, the whole of this apparatus, however, being mounted upon a switch panel, to which the electrical supply will be connected. The welding tool, which is shown in Fig. 8, consists essentially of a combined solenoid and air cylinder provided with the necessary accessory piston, piston-rod and solenoid core, to the outer end of the latter of which is attached the holder for the stud, tube or other fitting, which has to be welded. A piston-valve chamber forms part of the main cylinder casting, the valve itself being operated from a small solenoid, mounted upon the casting as shown.

The Type B welding tool is intended to be attached to, though insulated from, the spindle of a powerful drilling or other suitable machine, which has to be sufficiently rigid to withstand the powerful thrust exerted by the piston of the welding tool when subjected to the maximum air pressure which can be supplied. The size of welding tool shown will deal with work requiring currents up to 1 500 amperes, and for electrical supply purposes a motor-generator such as that described in detail later in the paper will be used.

The air-supply arrangements for the Type B apparatus

have required careful consideration, for the rather unusual reason that the quantity of air required is so small. As will be seen, it is only necessary to supply sufficient compressed air per weld to fill up the small

which keeps fully charged a small air receiver interposed between the compressor and the welding tool. This receiver is equipped with an adjustable relief valve which can be set to suit any pressure up to the maxi

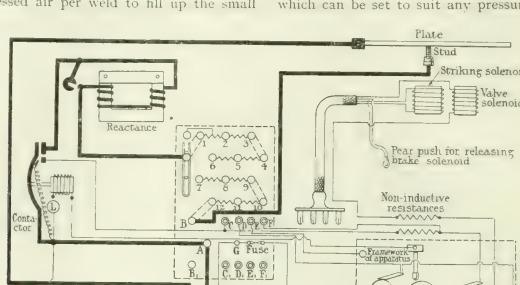


FIG. 9.—Diagram of connections for Type B Cyc-Arc electro-pneumatic welding apparatus.

cylinder of the welding tool and, as the type of weld which this apparatus will deal with is not likely to be effected at a greater rate than two welds per minute, the maximum amount of compressed air required per

mum capacity of the compressor which it is desired to use for any particular class of welding work. The motor-driven compressor, which is extremely small and compact, is fixed as close as possible to the welding

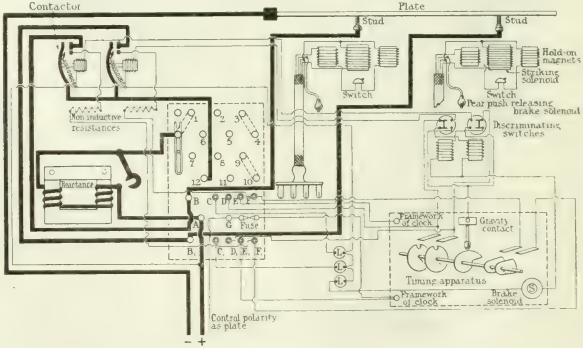


FIG. 10.—Diagram of connections for dual-control apparatus.

minute will only be double the capacity of the cylinder, i.e. less than 0·05 cubic foot. The kind of compressor plant proposed to meet these rather unusual requirements is of a small motor-driven tyre-inflator type,

tool, and will be capable of delivering considerably more than the maximum demand for air at a maximum pressure of 150 lb. per square inch. A flexible connection has, of course, to be provided between the

receiver and the inlet valve of the welding tool, to allow for the necessary movements of the latter during welding operations.

Fig. 9 shows the connections of the Type B apparatus.

(4) Dual-control System.

The use of the "Cyc-Arc" apparatus, modified to operate on the dual-control system, enables its output of work to be doubled, with only about a 25 per cent increase in the cost of apparatus. Furthermore, this doubling of output can be obtained without any appreciable increase in the size or cost of the welding supply plant.

The dual-control system enables the welding tools to be operated alternately by two separate operators from a single controller. The controller, however, is fitted with a pair of solenoid-operated discriminating switches, as well as with additional contactor, non-delaying or interfering with one another in any way, and thus make double the number of welds possible with a single-operator equipment.

This system and apparatus, which will be found extremely advantageous for use, more particularly on repetition work in large quantities, enables two operators to work at the rate of 80 to 100 welds per hour with the portable apparatus, and at a rate of over 200 welds per hour with the fixed machine adaptation of the welding tools.

The dual-control system and apparatus, though fully protected by patents, has only recently been perfected for use in the standard Type A welding apparatus.

(5) Results of Welding Experiments and Tests.

We have already stated that, when dealing with studs or plates of varying size, or in the case of different metals, it is necessary to alter the welding current as

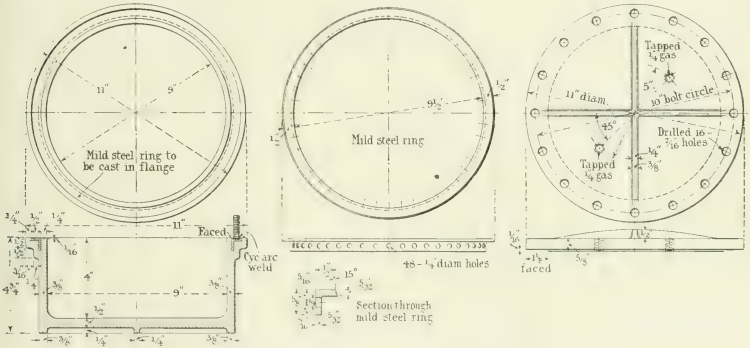


Fig. 11.—Cast-iron test-box and cover (with Cyc-Arc welded studs).

inductive resistance and accessories, as compared with a controller for a single-operator set.

The function of the discriminating switches, which are operated by the ordinary action of the push-button control on the welding tool, is to permit of a welding operation being effected by only one welding tool at a time, during which operation the other tool is completely and automatically isolated and thus put out of action. The hold-on magnets of the welding tools are, however, quite unaffected by this arrangement. Fig. 10 shows the Type A apparatus with two portable-type welding tools connected in accordance with the dual-control system. Owing to the extremely short overall time required to make each weld, viz. 7 seconds, compared with the time taken to remove the welding tool after the completion of the weld, and to replace it in another position with a fresh stud in the holder ready for welding, two operators can use two welding tools alternately on the dual-control system, without well as the time of operation, and that the successful results obtained by this system of welding are due mainly to the method of automatic control and accurate timing of the cycle of operations by the means we have described. By the use of the method and apparatus in question, a long series of investigations have been carried out with a variety of welds, leading to conclusive and consistent results, and it has been possible to draw up a table of the adjustments of current and timing necessary for the welding of different sections to varying thicknesses of plates, and also with relation to the welding of different metals. Our investigations have shown that perfect welds can be obtained between naval brass or manganese-bronze studs, and steel, iron, or brass plates. Equally satisfactory welds are obtained if the iron or steel is galvanized, provided that the zinc deposit is not unduly thick. Surprisingly good and strong welds can also be made with brass tubes on to steel plates, and the latter may be less

than 30 mils in thickness. Excellent welds can also be made on to spring steel. When welding brass tubes $\frac{5}{16}$ inch in diameter on to steel plates about 0·03 inch thick, the time during which the arc is maintained is almost incredibly short, viz. only 0·1 second. An interesting action which contributes materially towards the strength of the weld takes place when welding such tubes. Sections of these welds show that the molten brass has risen into the interior of the tube at its base in each case and formed a solid section for an appreciable height.

We attribute this useful effect partially to the fact that the air pressure in the tube is less than atmospheric pressure at the moment the tube is returned to the plate at the end of the cycle of operations, the diminished pressure in the tube being caused by the heat of the arc. Although it is quite possible by means of the "Cyc-Arc" process to weld studs on to cast iron, it will be appreciated that, mainly on account of the weakness of the cast metal, the result is necessarily unsatisfactory. We have therefore introduced a method of construction which should prove useful for the flanges of cast-iron casings, engine cylinders, etc. As shown in Fig. 11, a mild-steel angle or tee having holes punched through the portion which projects into the casting is placed in the mould near the centre-line of the flange, the casting being formed round it and leaving nearly flush with the face of the flange the surface of the mild steel angle or tee to which the studs are to be welded.

Another interesting and valuable application of the "Cyc-Arc" process is for the tipping of machine tools. By this means it is possible to weld with surprising strength small pieces of high-speed steel on to ordinary carbon-steel shanks. Notwithstanding the great difference in the hardness of these two steels, and the great stresses set up due to contraction on cooling, the welds obtained are extremely reliable and satisfactory. It is necessary, however, to anneal the tool as soon as possible after tipping before attempting to grind or work on it in any way. It is interesting to note that unless this is done the very act of stamping the tool before annealing for the purpose of marking it is liable to cause the high-speed steel to fracture near the weld. After annealing and hardening, however, the weld will be found capable of withstanding any load within the capacity of the tool itself.

The following is the report of a test made by Messrs. Vickers, Ltd., on such a turning tool:—

Turning Tool made by "Cyc-Arc" Welding.

Description of tool.—Shank 1 inch square. Vickers "A" steel. Tip $\frac{3}{8}$ inch diameter. Vickers high-speed vanadium.

Treatment.—Annealed after welding. Ground to shape. Hardened and re-ground to sketch.

Result.—The weld has proved to be entirely sound and is capable of resisting any load and cutting stress within the capacity of the tool steel itself.

Cutting tests.—Commencing with a light cut upon axle steel, the speed was increased to 124 feet per minute until the tool required grinding. It was then transferred to tyre steel and, with a speed of 38 feet per minute, the weight of cut was increased up to a removal rate of over 2 lb. per minute. On nickel chrome steel (about 55 to 60 tons maximum stress) the speed was gradually increased from 20 to 40 feet per minute, the rate of removal reaching nearly $1\frac{1}{2}$ lb. per minute.

Finally, on a hard nickel chrome billet (70 tons maximum stress), the tool was set into a depth of 0·17 inch, so that it was cutting half round the section, thus fully loading the tool. The weld remained intact even after the tool nose had become bluntened.

Various other brands of high-speed steel other than vanadium steel have also been welded by the "Cyc-Arc" process to ordinary carbon or mild steel shanks for making machine tools.

As already mentioned, in the case of screwed studs welded to ships' bulkheads the experience gained from destructive tests has shown that fracture should invariably take place in the screwed part of the stud and not at the weld, thus demonstrating that the latter is stronger than the former.

When first adjusting the timing and current for any particular run of work, we advocate the application of such destructive tests of trial welds. It will be found that the correct settings can be quickly obtained. We have found, however, that the adjustment of the timing and current is open to a certain latitude without adversely influencing the strength of the weld.

The following are the results of tensile tests on "Cyc-Arc" welds made at a recent demonstration at

WM. DENNY & BROS.' TESTING HOUSE, DUMBARTON.

Tests made for Demonstration Purposes, 16th June, 1921. Welding Screwed Brass Studs $\frac{1}{2}$-inch Diameter on Bar of Mild Steel by the "Cyc-Arc" Welder.

No. of Samples	Material	Article from which Test-piece was made	Diameter of Pin	Area	Maximum Load			Remarks
			in.	sq. in.	lb.	tons	tons/sq. in.	
1	Brass and mild steel	$\frac{1}{2}$-inch diameter brass pin welded to steel rod	0·495	0·192	6 600	2·95	15·38	Pin broke, weld not broken
2	Brass and mild steel	$\frac{1}{2}$-inch diameter brass pin welded to steel rod	0·495	0·192	7 250	3·24	16·90	Pin broke, weld not broken
3	Brass and mild steel	$\frac{1}{2}$-inch diameter brass pin welded to steel rod	0·495	0·192	7 300	3·26	17·00	Weld not broken

the well-known shipyard of Messrs. Wm. Denny & Bros., Dumbarton. The tests were made by the firm's testing staff and in their own machine, and the mild steel bars upon which the test welds were made were also supplied by the firm.

Below are given the results of tensile tests made by Messrs. Avery's staff with their own testing machines, at a recent exhibition at Olympia, on various "Cyc-Arc" welds. The majority of these welds were made with demonstration apparatus at the exhibition, which latter included one of the Brush Electrical Engineering Company's specially designed and constructed "Cyc-Arc" kinetic motor-generators, to which special reference is made later in the paper.

"Cyc-Arc" Weld Tests made by Messrs. Avery at the Shipping Exhibition at Olympia, 17th to 28th September, 1921.

Naval Brass (N.B.) or Manganese-Brass (M.B.) Rods Welded to 1-inch Diameter Mild-steel Rods.

Diam. of Stud	Material	Actual Diameter at Weld	Area	Actual Breaking Load	Breaking Stress
in.		in.	sq. in.	tons	tons/sq. in.
$\frac{5}{8}$	N.B.	$\frac{5}{8}$	0·3068	8·06	26·3
$\frac{5}{8}$	M.B.	$\frac{5}{8}$	0·3068	7·75	25·25
$\frac{1}{2}$	N.B.	$\frac{1}{2}$	0·1963	5·79	29·45
$\frac{1}{2}$	M.B.	$\frac{15}{32}$	0·1725	4·82	27·9
$\frac{3}{8}$	N.B.	$\frac{3}{8}$	0·1104	2·54	23·0
$\frac{3}{8}$	M.B.	$\frac{3}{8}$	0·1104	2·07	18·75
$\frac{1}{4}$	N.B.	$\frac{1}{4}$	0·0491	1·69	34·5
$\frac{1}{4}$	M.B.	$\frac{1}{4}$	0·0491	1·71	34·8

Naval Brass Studs to 1-inch Diameter Mild-steel Rods.

Diam. of Stud	Bottom of Thread		Actual Breaking Load	Breaking Stress
	Diameter	Area		
in.	in.	sq. in.	tons	tons/sq. in.
$\frac{5}{8}$	0·5086	0·2032	6·22	30·6
$\frac{1}{2}$	0·3933	0·1215	3·69	30·4
$\frac{3}{8}$	0·2950	0·0683	1·93	28·2
$\frac{1}{4}$	0·1860	0·0272	0·74	27·2

Brass Tubes on $\frac{1}{4}$-inch Mild-steel Plate.

Outside Diameter	Inside Diameter	Area	Actual Breaking Load	Breaking Stress
in.	in.	sq. in.	tons	tons/sq. in.
$\frac{1}{2}$	$\frac{3}{8}$	0·0859	1·59	18·5
$\frac{11}{32}$	$\frac{1}{4}$	0·0437	0·83	18·75

These results speak for themselves, and have exceeded our best anticipations, showing that, with proper adjustment of the "Cyc-Arc" apparatus, welds between different metals of dissimilar section are obtainable of a mechanical strength which cannot be approached by any other method of welding.

At various times, oscillograph records have been taken showing the variations in current and voltage during the cycle of operations necessary to make a "Cyc-Arc" weld. While it is not proposed to remark upon the results thus obtained and the deductions made from them, graphs have been prepared (see Fig. 12) which it is thought will be of interest, and which indicate approximately the current and voltage variations taking place in welding $\frac{1}{2}$-inch diameter naval brass studs to mild-steel plate. The supply was taken from a 110-volt direct-current generator which, however, was considerably overloaded during the short periods of the welds, the full time for welding being well under 2 seconds.

(6) Metallurgical Considerations.

The great strength of the welds obtained by this process of welding led us originally to the conclusion that this might reasonably be attributed to three causes:—

(1) Absence of oxides in the weld.
(2) Extremely local heating in the region of the weld.
(3) Penetration (in each direction) of the metals to be welded.

Since then, micro-sections have been cut through a number of welds and examined, photo-micrographs having been taken at a magnification of 50 diameters, and the above conclusions have been definitely confirmed.

The following are the reports of some of these examinations made by Messrs. Vickers, Ltd., at their River Don works at Sheffield.

Brass on mild steel.—A micro-section was cut through the brass and mild steel, as shown in the photo-micrograph. The weld was an exceedingly good one, and contained no oxide along its path. On the steel side of the weld the heating had produced structural changes which persisted for a depth of only about 0·05 inch from the weld. Adjoining the weld was a layer about 0·008 inch across, consisting of complete solid solution, and containing fine cracks filled with brass which had run in from the weld. This area very probably contained dissolved copper and had been fused. Below this another band was found consisting of martensite, with a little ferrite between the crystals. At one end of the weld, the solid-solution belt curiously ran out to the surface, with the martensite structure on both sides of it, as indicated on the figure, the shaded portions representing the martensite. Below the above layers the pearlite had dissolved to some extent in the ferrite, and was present as dark troosto-sorbite areas which quickly gave place to pearlite areas which had been transformed in situ to sorbite. Below this, at a depth of 0·05 inch from the weld, the normal mild steel was found.

On the other side of the weld the brass showed a layer about 0·01 inch thick which had evidently been partially melted, and having a fine-grained confused

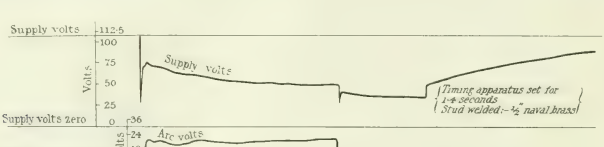
structure. Below this the normal structure of the brass was found.

Photo-micrographs were taken at a magnification of 50 diameters to show:—

(*a*) The structure of the brass and the steel at the weld.
(*b*) The structure of the steel.

High-speed steel on mild steel.—The specimen, which had been locally hardened at the weld, was first annealed at 850° C., this having the effect of removing structional variations due to the local heating, so that only the nature of the joint remained for examination. As shown by the sketch, there was much melting of the high-speed steel, especially on one side where the melted joining material is full of blow-holes, due, no doubt, to action between carbon and the original steel surfaces being connected by a layer of fused material which varied in thickness from 0·025 inch to 0·0065 inch. This layer contained a few blow-holes, and consisted of very pale solid solution with a little free ferrite, evidently containing very little carbon. On both sides the mild steel consisted of martensite with troostite borders and a little ferrite to a depth of about 0·02 inch to 0·025 inch. Below this on the plate side, for a further 0·005 inch, the pearlite areas were changed in situ to troostite, often with martensite kernels. Beyond this the structure was normal.

On the stud side, the heating effect persisted to a somewhat greater depth, in all about 0·055 inch. For about 0·025 inch the structure consisted of martensite with a little free ferrite with troostite areas enclosing martensite kernels. Beyond this the structure passed somewhat abruptly into the normal pearlite and ferrite



Supply and arc voltages at welding apparatus

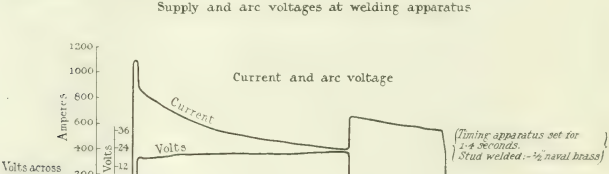


FIG. 12.—Showing current and voltage curves on a Type A Cyc-Arc welding set. Supply: 110 volts d.c.

surface scale. On the other side the joint was quite good. Two fine longitudinal cracks, the longer being about 0·15 inch in length, were found in the high-speed steel. These were associated with original slag inclusions close to the weld, but were, no doubt, developed by the sudden changes of volume during welding.

A photo-micrograph was taken at a magnification of 50 diameters.

High-speed steel on "A" steel.—This weld had not been preserved intact, but was broken as shown in the sketch. After softening at 850° C., it was seen that the material adhering to the "A" steel was fused high-speed steel which, as shown by the fracture, was full of blow-holes. Where contact was made, the weld was a good one and free from oxide. A photo-micrograph similar to the others was taken.

Mild steel on mild steel.—A micro-section cut through this specimen showed a very good joint, the two mild-structure. A photo-micrograph was taken at a magnification of 50 diameters.

Manganese-bronze stud welded on to Vickers' high-speed vanadium steel.—A manganese-bronze stud welded on to a high-speed vanadium-steel bar $\frac{7}{8}$ inch × $\frac{1}{4}$ inch section, was received for examination per Mr. Basil Gray, 15th April, 1921. A micro-section cut through the weld showed, after polishing, an exceedingly good joint between the steel and the manganese bronze, no oxide being found. A feature of the section was the irregularly-shaped intrusion of high-speed steel running into the bronze. Detached particles are shown in the photo-micrographs at a magnification of 50 diameters, but these were probably connected to the main bulk, a cross-section of the end of the arms being seen on the micro-section. After etching, the majority of these areas consisted of well-developed austenite containing acicular markings. Some areas were much more darkly etched, but often contained small austenite

areas. It was evident that these areas had been partially melted (see Fig. 13).

Structural variations to a maximum depth of 0·04 inch from the weld were found in the high-speed steel. A layer about 0·01 inch deep, adjacent to the weld, consisted of solid solution, and showed indications of partial melting along the surface. Some few short, open cracks were found in this layer, but did not extend further inwards from the weld, as shown in the photo-micrographs. Below this, for about 0·05 inch, the background of the structure was etched distinctly more darkly than the normal structure. It was evident that the local heating had not been much above the normal change-point in this layer, and the cooling rate had not been sufficient to produce any considerable hardening.

At the weld, the bronze to a depth of about 0·015 inch showed a very much finer-grained structure than the normal. This was due to the intense local heating, but the structure did not suggest that actual fusion had taken place. The bronze sphere at one end of the weld showed a dendritic structure and had been fused.

Below this layer, for a further 0·02 inch, the structure of the bronze showed some slight difference from the normal, the relative proportions of the constituents of the bronze (or rather of the brass, since manganese-bronze is really a type of brass) being altered to some extent. The general structure of the bronze is shown in a photo-micrograph.

To sum up, therefore, it would appear as a result of these investigations that the effect of heating does not extend for more than 0·05 inch from the weld. This can be seen from the structural changes in the metal. There are also indications of a fused mixture on each side of the weld to a depth of about 0·01 inch, but not much penetration beyond this. We therefore attribute the great strength of welds obtainable by this system to penetration combined with the extremely local heating effect and the absence of oxidation. The heating is so local that the structure of the main body of metal is unaffected, and is therefore not likely to start cracks from the affected portion. This is important from a metallurgical point of view.

(7) Practical Applications.

As has been previously indicated, this process of electric welding was originally developed to meet the requirements of naval construction. A large number of fittings, as well as many miles of electric cable and other systems of communication, are fixed to bulkheads and on the underside of decks. The method employed in the past has been to drill and tap the bulkheads where necessary, and to secure the fittings, cable clips, etc., in position by means of studs screwed into the tapped holes, these studs being rendered as watertight as possible with red-lead grummets placed under the head of the nut on the reverse side of the bulkhead. Notwithstanding the precautions taken to ensure that each hole is rendered watertight after the screwing-in of the stud, it has been found in practice that vibration and shock due to gun-fire causes these studs to work loose, and thus a large number of the holes become no longer watertight.

The degree of risk entailed from the above causes will be appreciated from the fact that on a ship of the size of H.M.S. "Queen Elizabeth," at least 350 000 $\frac{1}{4}$-inch studs have been fixed into the bulkheads, etc., and each may be considered to be a source of potential weakness so far as the watertightness of the various compartments is concerned. The drilling of long lines of holes through the bulkheads must also obviously weaken the latter.

With the "Cyc-Arc" method of welding, neither is the watertightness of bulkheads impaired nor the structure weakened. Mechanical tests have shown

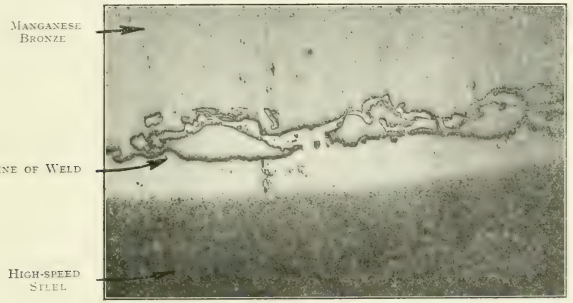


Fig. 13.—Electric arc weld. Manganese bronze on high-speed steel. Magnified 50 diameters. Etched by picric acid.

that plates to which studs have been welded by this system have actually been reinforced by such welds.

The above considerations also apply to merchant-ship construction, and are of special importance in connection with oil-tank steamers. It has, in fact, been found that there is considerably more scope for the use of the "Cyc-Arc" process on merchant-ship construction in making all kinds of minor attachments, there being additional advantages in ease and rapidity of work, on account of the larger and more open compartments, and generally more accessible positions for welding purposes.

It should be noted that Lloyd's Register of Shipping has fully approved of the "Cyc-Arc" process for such use in ship construction.

Apart from the advantages just mentioned, there is also great economy in time and labour. At least 10 studs can be welded in position in the time occupied in fitting one bolt or screw by the ordinary methods of drilling and tapping, and, with an average run of work, large studs can be welded at the rate of at least 40 per hour.

The cost of fixing studs by this method is less than one-quarter that of screwing them by the ordinary method.

The condition of the metal surface to which studs or other fittings are welded, should receive attention when the surfaces have been painted, red-leaded, or are oily or greasy. In such cases it is necessary to clean the surface over a circular patch about 1 inch diameter, and the quickest method we have found of doing this is by means of the paint removers used in commerce. Unless the iron or steel surfaces to which the welds are being made are very heavily rusted or pitted, no special preparation of the surface is necessary, but the preliminary use of a wire brush is advisable for removing rust or scale.

It is interesting to note that the fact of the surfaces being wet is not disadvantageous to this process of electric welding; in fact, perfectly satisfactory welds can be made under water.

Particular attention is called to the quality of the welds between brass and steel, iron, or brass, not only as regards to mechanical strength, but also electrical conductivity.

This feature should be of the utmost interest to electrical engineers and manufacturers in general, for it indicates a means of making electrical connections of a quality hitherto unattainable, in a perfectly simple and rapid manner.

A striking illustration of such application is in the use of this process for all kinds of electrical bonding, particularly on steel and iron structures, and consideration is now being given to its use for various kinds of lightning-protection connections in naval work. In addition, we think that by its use an ideal method of rail bonding is available, for which there should be great scope in the electrification of railways, which is now proceeding so rapidly in various parts of the world. We have made certain definite proposals in this direction, and have actually put them into practice experimentally.

One method we suggest for the consideration of the traction specialist, is to weld, by means of the "Cyc-Arc" process, a substantial size (say $\frac{3}{8}$ inch or $\frac{1}{2}$ inch diameter) of short-shouldered naval brass stud on to the web of each rail near the joint, and then complete the bond by means of copper or brass strip attached to the studs, either by cold riveting, or by nuts supplemented with a suitable locking device.

Another method is to weld by the same process on to each rail near the joints, naval brass thimbles, previously tinned preparatory to sweating into them flexible circular copper bonds. This latter method has been objected to on account of the sweated joints, but we are inclined to think that it is worth consideration if the work is done thoroughly and in a proper manner.

We shall be glad to hear opinions expressed on these proposals.

It is obvious that, apart from ship construction, electric bonding, etc., this system of welding is capable of application in many industries. The following is a list of the more apparent industries in which the process and apparatus can advantageously be used:—

Ship work in general, primarily to maintain water-tightness.
Locomotive construction.
Crane construction.
Steel coach, carriage or wagon construction.
Motor vehicle construction.
Light vehicle construction, e.g. perambulators, hand-carts, cycles, etc.
Boiler mountings.
Tanks.
Floating buoys.
Tubular structures, e.g. heaters, coolers, radiators, etc.
Rail and all kinds of electrical bonding.
Aeroplane and airship construction.
Agricultural implement construction.
Bedsteads.
Domestic utensil manufacture.
Steel office furniture.
Lock and safe manufacture.
Watch and clock manufacture.
Tool-making.

(8) Special Machines for Supplying Power for Direct-current Welding.

The "Cyc-Arc" process differs from the majority of other welding processes in the fact that each weld takes a relatively heavy rush of current for an exceedingly short time. As, in addition, the supply pressure need not exceed 60 volts, an extremely small quantity of energy is required per weld, e.g. a $\frac{1}{2}$-inch diameter stud weld takes 12·5 watt-hours, or 1/80 kWh, while a $\frac{1}{4}$-inch stud weld takes only 2 watt-hours, or 1/500 kWh.

Although the Type A welding apparatus is being operated satisfactorily direct from the ordinary 60- or 100-volt direct-current welding supply mains on fairly large installations where the supply mains and plant are of considerable capacity, it has, on the other hand, been found necessary to design special supply plant

for use in conjunction with the "Cyc-Arc" apparatus in the following cases :—

(A) Where the existing welding supply plant is of small capacity.
(B) Where no welding supply plant is installed, but electrical supply is available.
(C) Where no electrical supply is available.

To meet such cases as (A), special "kinetic generators" have been designed, and can be supplied at a relatively low cost. These generators, the rating of which is quite small relatively to their momentary loads when welding, are fitted with flywheels. Each generator is supplied with a starter, so that it can be run as a motor from the welding supply mains, to which it should be connected as near as possible to the "Cyc-Arc" apparatus which it has to supply.

In the intervening periods between welds, the machine is merely motoring "light" from the welding supply mains, but the moment a weld takes place it automatically becomes a generator, supplying practically the whole of the welding load, owing to the combined effect of the flywheel and the special design and arrangement of its field windings.

The current taken from the welding supply mains when supplying the Type A welding apparatus through this special kinetic generator need not exceed 50 amperes, while its motoring current when running light is only from 12 to 20 amperes.

The consequent advantages in minimizing peak loads on the welding supply plant, and in reducing the size of the supply mains necessary for "Cyc-Arc" welding, are obvious.

To meet all cases such as (B), where no suitable welding supply is available for the "Cyc-Arc" apparatus, special kinetic motor-generators have been designed and can be supplied at a moderate cost.

The fundamental principles of the design and operation of these motor-generators are the same as those of the above-described kinetic generator, but each machine can be supplied with a motor designed to suit, not only the voltage, but also the kind of electricity supply which is available, whether direct current or alternating, three-phase or single-phase.

The reason that such motor-generators can be supplied at a cost not greatly in excess of the price of the kinetic generators, is that the driving motors are only of approximately 3 kW capacity.

These motor-generator sets, when running light from the supply mains, take about $1\frac{1}{2}$ kWh per hour, this amount being increased to less than $2\frac{1}{2}$ kWh per hour when welding the largest size of stud at the maximum possible rate with the Type A apparatus. In addition, attention is called to the fact that the maximum load on the supply mains need not exceed 5 kW, i.e. 23 amperes at 220 volts d.c., 11·5 amperes at 440 volts d.c., or 6 amperes at 440 volts a.c., three-phase. The complete suitability of such a plant for supply from the smallest power mains likely to be found installed in any works or shipyard is thus also obvious.

For cases such as (C) where no electricity supply is available, e.g. works or repair shops in isolated places, or where "Cyc-Arc" welding is required to be done by means of a portable engine-driven plant, the kinetic generator has been adapted for use with small petrol, paraffin or steam engines, and can be also supplied in portable form. The size of engine required for the Type A apparatus is only from 5 to 6 h.p., the average load when welding at a maximum rate being about $2\frac{1}{2}$ h.p., and the petrol consumption being less than 1 gallon per day of 8 hours, during which at least 400 welds should easily be made.

The kinetic generators can also be supplied and fitted with extended shaft, pulley and additional bearing, making them quite suitable for belt-drive from ordinary counter-shafting.

With reference to the special design of the kinetic generators, it should be noted that direct current is supplied to the "Cyc-Arc" welder under conditions the characteristics of which are unusual, that is to say, in such a manner that the circuit should be devoid, or substantially devoid, of the effect of the inductance of series coils at the moment of striking the arc, while the advantage of cumulative compounding for maintaining the voltage during welding operation is considerable. These objects are achieved by employing a machine comprising a field system, and an armature with two windings and two commutators, each winding being connected to a separate commutator. The brushes of one commutator are coupled in parallel with the brushes of the other commutator to the leads supplying the welder, series excitation being provided by a winding in the circuit of one only of the armature windings, and the shunt winding being conveniently, though not necessarily, excited from the same side of the system.

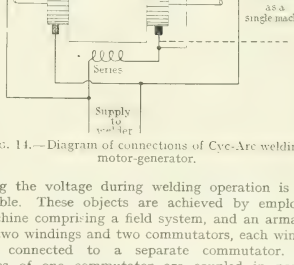


FIG. 14.—Diagram of connections of Cyc-Arc welding motor-generator.

As will be seen from Fig. 14, the generator has a double winding, and the common field is so arranged that one winding strikes the arc while the other gives the cumulative compounding for maintaining the voltage during the weld. The arrangement also facilitates self-excitation and maintains a steady supply of current to the solenoids, as well as affording a means of compensation for any drop in speed to enable the flywheel energy to be utilized.

The generators are designed for a speed suitable for driving by induction motors having a synchronous speed of 1 500 r.p.m. The same speed is utilized when

TESTS CARRIED OUT BY THE BRUSH ELECTRICAL ENGINEERING COMPANY ON "CYC-ARC" KINETIC MOTOR-GENERATOR SETS.

D.C. Motor. Type H.O.5. Reference No. 29 845/19 470.

Load	Pressure	Current	Speed	Rating
b.h.p.	volts	amps.	r.p.m.	
9	220	38	1 500	Continuous 60 welds per hour
3 to 6	220	14·5 to 25·5	1 500 to 1 280	Continuous 60 welds per hour

D.C. Motor-generator. Type H.G.O.9. Reference No. 19 811/19 469.

Output	Pressure	Current	Speed	Rating
kW	volts	amps.	r.p.m.	
30	60	500	1 500 to 1 280	Sixty 2-second welds per hour
6	60	100	1 500	Continuous

TEST ON WELDING MOTOR-GENERATOR SET UNDER CONDITIONS CORRESPONDING TO THOSE OF STUD WELDING.

H.O.5 Motor No. 19 470. *H.G.O.9 Generator No.* 19 469.

As a Motor-Generator Set.

Generator: Speed			Generator: Terminal Pressure during Load Period				Generator: Current in Welding Circuit		Motor: Line Pressure	Motor: Line Current		Remarks
Before Load	At End of Load	Period of Load	*1	2	3	4	1	2		Min.	Max.	
r.p.m.	r.p.m.	secs.	volts	volts	volts	volts	amps.	amps.	volts	amps.	amps.	
1 575	1 325	2	59	55	66	60	552	460	220	12	21	
1 585	1 365	2	59	56	67	61	552	480	220	12	21	
1 585	1 365	2·5	60	57	67	59	540	480	220	12	25·5	Average time for set to recover speed: 60 seconds
1 625	1 425	2	61	57	68	62	448	400	220	12	20	
1 625	1 485	2	60	58	69	64	340	320	220	12	18·5	
1 585	1 505	2	60	59	70	66	292	280	220	12	16·5	
1 575	1 525	3	60	59	68	67	148	148	220	12	15·5	

A circuit breaker was then inserted in the welding circuit, the set was run at full speed, the generator was excited to 60 volts, and then dead short-circuited across the welding mains. The set withstood this test satisfactorily.

TEST AS FLYWHEEL GENERATOR FLOATING ACROSS 60-VOLT MAINS.

(*Note:* For the purpose of this test the motor was entirely disconnected electrically, although remaining direct-coupled mechanically to the generator.)

Speed: Before Load	Speed: At End of Load	Period of Load	Terminal Pressure in Welding Circuit during Load Period: *1	2	3	4	Current in Welding Circuit: 1	2	Line Pressure	Supply Current: 2	3	4	Max.	Remarks
r.p.m.	r.p.m.	secs.	volts	volts	volts	volts	amps.	amps.	volts	amps.	amps.	amps.	amps.	
1 525	1 265	2	60	58	66	57	520	520	60	40	0	−8	140	Recovered speed in 45 seconds
1 505	1 285	2	60	59	66	56	520	520	60	40	0	−10	126	
			Readings on Light Load, as Flywheel Generator.											
1 360		—	60				—		60	35				Full field
1 500		—	60				—		60	38				

* Numbers over columns indicate sequence of readings.

the generator is driven by a direct-current motor. A cast-steel flywheel is mounted between the motor and the generator, and the drop in speed during a full 2-second weld taking 500 amperes at 60 volts is about 15 per cent. The regulation of these generators is based on the assumption that there is a definite period between each weld in which to restore the energy of the flywheel.

Any undue increase in the motor load owing to the drop in speed of the machine is prevented by the compound winding of the direct-current motor, or by the use of a slip resistance in the case of an induction-motor drive.

For stud welding, the input of the motor varies up to a maximum of 5 kW at the end of a 2-second, 500-ampere, 60-volt weld. The current peak is therefore less than one-seventh of that required by a set not provided by a flywheel.

Extracts are given from the test-reports of the Brush Electrical Engineering Co. on the first kinetic motor-generator of the above described type which they constructed for "Cyc-Arc" welding.

While it is anticipated that these tests will be self-explanatory in view of the information that has been given, particular attention is drawn to the following points:—

(*a*) In the case of the motor-generator; the extremely low value of the motor supply current, while making even the largest welds.

(*b*) In the case of the generator only, "floating" on 60-volt supply mains; the interesting fact that no current whatever is taken from the mains during the major portion of the welding period, and that the machine, while supplying the whole of the welding current required, is, in addition, actually re-generating into the mains. This is on account of its heavy over-compounding, combined with the fact that it is coupled to a flywheel.

(9) Considerations for the Use of Alternating Current for the "Cyc-Arc" Process of Electric Welding.

We anticipate that the fact that we have not yet introduced alternating current for use in this process and apparatus will occasion some surprise. We have not, however, entirely neglected both consideration and experiment in this direction, with the result that we feel quite sure that alternating current will ultimately be used, more particularly in welding considerably larger work than it has hitherto been possible for us to undertake. There are, however, difficulties to be overcome in order to obtain satisfactory "Cyc-Arc" welds by means of an alternating-current supply. As is well known, there is no difficulty in making metallic arc welds of good quality with an alternating-current supply, and it will be readily understood that the difficulties in connection with our welding process, when operated from such a supply, are not connected with the satisfactory completion of the weld after the arc has been struck, but are rather associated with the well-known difficulty and uncertainty of striking an alternating-current arc. As successful welding by the "Cyc-Arc" process mainly depends upon the accurate, instantaneous, and uniform timing of the arc under the control of the automatic timing apparatus, in order that it can be maintained for a uniformly accurate period, the troubles liable to be produced in "Cyc-Arc" welding on account of this difficulty will be understood. Satisfactory means have, however, been evolved for overcoming these difficulties, which it is not proposed to discuss at the present time, owing to the fact that experimental demands in other directions in connection with the process have prevented the investigation into its operation with alternating-current supply from being as fully advanced as we had anticipated and hoped for. From information we have already obtained, however, we consider that it will be generally advantageous to use direct-current supply for small work, and that it will probably be worth while constructing the modified apparatus necessary for use with alternating-current supply only when using currents of well over 1 000 amperes.

(10) Conclusion.

In conclusion, we believe that we are justified in stating that the process which we have described and are also demonstrating solves the problem of electrically welding metals of widely differing character and section.

We hope that the apparatus we have devised in connection with this process will find a useful application in many industries. Some of these applications are obvious, but many others are undoubtedly unknown to us at the present time. We shall welcome, therefore, any suggestions for the application of this process of automatic electric welding.

It will probably be a matter of some surprise that reference has been made so fully in this paper to the welding of widely dissimilar metals, and that so little has been said with regard to welding iron and steel. We have found in the course of our investigations that the problem of welding these metals offered exceptional difficulties and had to be studied on special lines. Our investigations in connection with this problem are, however, almost completed, and we hope to publish the resulting information in the near future. We are pleased to be able to state that this difficult problem has now been solved and that, by means of our process and apparatus, ferrous metals of widely different section and composition can be directly welded with exceptionally good results.

To satisfy the curious as to the meaning of the words "Cyc-Arc," we may explain that they are derived from the essential feature in our process of welding, viz. the "*Cycle* of operations necessary for the satisfactory formation, maintenance and termination of the *Arc*."

We are indebted to Messrs. Vickers, Ltd., for their generous assistance in carrying out the photo-micrographic examinations of various welds, and for their metallurgical reports upon the same.

We are also indebted to the Brush Electrical Engineering Company for their able co-operation in the design and construction of the kinetic generators to which reference has been made in the paper.

Discussion at The Institution, 1st December, 1921.

Captain R. J. Wallis-Jones: I think that the explanation given in the paper, i.e. that the strength of the weld between the brass stud and the steel plate is to some extent due to the intergrowing of the metal, is very interesting, and the authors' experience in perfecting their apparatus illustrates most forcibly the importance of little details. In the welding of brass and copper it is of the greatest importance to be able to repeat exactly the conditions essential for welding, and I am reminded of an early difficulty which I experienced some years ago in attempting to weld copper wires by the resistance method. At that time there was no plant in operation in this country capable of successfully and commercially welding copper wires. The apparatus then available consisted of a self-exciting alternator and an automatic wire welder. I carried out a great number of experiments, and frequently obtained good welds, then a succession of bad ones would occur. I found that the trouble was due to the self-exciting alternator. The time during which the copper was subjected to the heat varied greatly. By substituting a separately excited alternator, or by connecting the welder direct to the supply mains, the difficulty was overcome and the use of the automatic welders for welding copper wire is now almost universal. I should like to ask the authors whether they have been successful in welding aluminium. It seems to me that this process should prove suitable for that purpose. The authors refer on page 136 to the previous impossibility of welding metals having widely different melting points, such as brass and steel. The Thompson system, however, enables such metals to be successfully welded. I was very interested in the shape of stud (shown in Fig. 2) that the authors have found to be most successful for welding brass to steel. It is very important that the materials to be welded are of the right shape. The various sections of tyres (shown on the slide) are difficult to weld; in fact, in the early days we were not able to weld them successfully, because the top portion frequently showed a crack where the surface should have been properly welded. This happened when the ends of the tyre were cut straight and butted face to face. The difficulty of welding the bend or top portion was overcome by cutting back the ends of the base at an angle. The top is then welded first and no difficulty is experienced in welding the tyre. I am referring now to "slow welding." The authors also refer on page 136 to the difficulty or impossibility of welding together surfaces of different sizes. A tramway-rail steel splice-bar or bond, shown on the next slide, has a small lozenge-shaped projection at each end, and a strip projection in the middle. One bond is placed horizontally on each side of the web of the rail at the joint. The bonds are gripped between the jaws of the secondary of a Thomson welder, outside the portion where the projections occur, and the smaller surfaces of the projections are welded to the larger surface of the web of the rail. Each weld is allowed to cool under the pressure of the jaws of the electrodes, which are squeezed together when the portions arrive at welding heat. Very successful bonding results are thus obtained. The next slide, shown as being of historical interest, was made from a photograph which Professor Elihu Thomson gave me in his laboratory at Lynn, and shows the first welder made on the Thomson or resistance-welding system. This crude machine consisted of a single turn, flexible copper secondary, with a primary coil, all surrounded by iron wire, together with devices to grip the rods to be welded, and an upsetting device.

Mr. J. R. Cowie: The authors have said that they are doubtful whether the studs made here to-night will withstand a tensile stress. Some months ago I had a demonstration of this process before the final timing apparatus was designed, and the samples I took away and had cut up and examined showed that an absolutely sound weld had been effected. Also, when subjected to shearing stress, the stud itself broke away before the weld. This demonstration took place just after the inauguration of the air pressure to get rid of the blow holes to be seen on one of the early slides. At that time there was another difficulty which has now been overcome, and I should like the authors in their reply to tell us how this was achieved. In the early experiment when welding on to thin section plates, the studs were not all of one length after the welds had been made is the revised timing apparatus the sole cause of the cure? We have seen how short a time it takes to make one weld, and a table showing what the cost would be for a certain definite number of welds of different sizes would, I am sure, be very useful.

Mr. T. F. Tate: The problem of welding dissimilar metals and metals of widely different cross-section is primarily one of temperature regulation. With the Thomson resistance process the method adopted is to give to the piece of the larger mass or lower welding point a smaller amount of projection from the clamps, the object being to obtain an equal temperature in both of the pieces or, in the case of dissimilar metals, to bring simultaneously both of the pieces to their respective welding temperatures. Similarly in T and angle welding it is necessary to adopt some means for ensuring a like result. For instance, two welding transformers may be used in one machine, one for pre-heating the larger piece or stem on to which the branch is to be welded at an angle, and the other for welding the branch to the stem. The work can also be done with one transformer by applying the current intermittently, but this requires a skilled operator. In welding a stud to a plate it is difficult to obtain an equal temperature in both parts to be welded, on account of the greater heat conductivity of the plate, and it is possible that this is one of the reasons why the initial experiments in welding steel studs to steel plates were not successful. Brass, on the other hand, is capable of being welded at a much lower temperature than steel, and, by making the steel plate positive and the brass stud negative, a distribution of heat is obtained which enables the weld to be made. This is not possible with alternating-current arc welding, as the temperature of the opposite poles is the same, and the effect of heat conduction in the plate again

comes into play. Nevertheless, I agree with the authors in anticipating that alternating current will eventually supersede direct current for stud welding, the method of obtaining the heat being probably some modification (e.g. flash welding) of the Thomson process.

Mr. B. A. M. Boyce: In connection with the second test on page 137 it will be noticed that the successive values of the supply current are 40 amperes, zero, 10, and finally 126 and 140 amperes after the welding circuit is broken. This is due to over-compounding. The compounding is the same as for the motor-generator test above and could with advantage be reduced in this case to approximately one-half, in which case the supply current would be more uniform. In a test of the motor-generator without the compounding winding the speed hardly dropped at all and the weld was a failure, showing that the set would not pick up the load in the necessary time. We have in view and under construction further developments which we hope will increase the efficiency still further and also reduce the cost.

Mr. A. F. Harmer: I should like to ask the authors whether this apparatus is suitable for welding sleeves on to a shaft. I assume at once that the sleeve would have to be split and put on in two operations. From time to time armature shafts get worn, and it seems quite unnecessary to waste an armature simply because this occurs. Provided that the area is not too great this particular system of welding would seem ideal, as the heat is so momentary that the armature windings would not be damaged.

Mr. E. M. Lacey (*communicated*): I do not think that the statement that the authors' process was the first used to weld together two sections of unequal size is strictly accurate, as I believe this was done several years ago by the disc resistance process, which is still used on a fairly large commercial scale. The authors on page 143 say that they consider screwing up the nut to fracture point to be the most satisfactory test of the weld. In the case of pipe lines on ships, etc., would not a shearing strain be the most severe test to which the studs would be subjected, or, where distance pieces are used, that of bending, which would of course be more important than the tensile test? On page 146 it is stated that a heavier current should be used on plates over a certain thickness. Would not this entail very frequent adjustment for ship work, as the plates vary considerably in thickness, and the construction is such that the distribution of heat would be more rapid in some places than in others, thereby tending to the making of defective welds? Also, in view of the possibility of incorrect adjustment in some cases, how is the operator to know that he is making good welds? Is there any external indication of a good weld? I should be glad if the authors would say what is the effect on the strength of the weld after the zinc has been vaporized by the arc, and about what proportion is lost. Also, does a slight variation in the composition of the stud, or impurities such as would be met with commercially, affect the strength of the weld? The weight of the apparatus is stated to be 18 lb., and this is somewhat heavy for one man to handle continuously. Have the authors experienced any trouble from this cause in actual practice?

Professor E. W. Marchant (*communicated*): With reference to the statement on page 136 as to the use of coated electrodes, the drawback to these electrodes, when used in connection with an automatic apparatus, is the accumulation of the slag formed during the process of welding. A man when welding is able to prevent pockets of slag from collecting and interfering with the uniformity of the welded material, but the automatic machine cannot do this, and the advantage gained in protecting the weld by a coating of slag is more than compensated by the lack of uniformity caused by these pockets. The welding of studs on to a plate is, of course, a different problem from that of welding two plates together, though the essential factors are the same. The method used by the authors, of very suddenly heating the end of the stud and the part of the plate to which the stud is to be attached, is an excellent solution of the problem. In order to get a thoroughly satisfactory job it is, I presume, necessary that the surface to which the stud is to be attached should be thoroughly cleaned in order to avoid the formation of slag. The process, when there is a very short time of contact for effecting the weld, is not very different from resistance welding, as it would seem to be very doubtful whether a real arc can be struck and extinguished in such a short time as 0·1 second. I should like to suggest that some further explanation of the curves in Fig. 12 should be given. In the upper curve the arc voltage falls to zero long before the supply voltage rises to its original value. I presume this is due to current continuing to flow through it from the supply after the weld is complete. It would make the diagram much more easy to follow if a current curve were introduced into it. In the lower curves, the current through the arc rises suddenly to about 1 100 amperes when the circuit is closed, and then, after a very short interval, presumably when the arc has been struck, falls to just under 900 amperes. At this instant the voltage increases suddenly from zero to about 18 volts. After an interval, the pressure across the arc falls to zero, whereas the current through the arc at this instant suddenly increases from about 400 to nearly 800 amperes. This occurs, presumably, when the weld is complete, current continuing to flow after the stud metal has adhered to the plate. It would be of value in connection with Fig. 12 if a diagram were given showing the connections of the circuit used in making the tests. The influence of reactance, referred to on page 141, must have been negligible when the oscillograms were taken, otherwise the current curve in Fig. 12 could not have risen so rapidly as it has done. I have taken a large number of oscillograms of currents and potential differences, including a great many in connection with some tests on arc welding that were made here, but I have not obtained curves similar to those shown in Fig. 17. This would appear to bear out the opinion that the process is not similar to ordinary arc welding.

Mr. R. T. Smith (*communicated*): On page 154 the authors point out that the process is applicable to the bonding of rail joints for railway electric traction and they showed examples of such bonding. For shoe contact rails the section of the rail and its conductivity may require the joint to be bridged by four

flexible copper bonds each having a cross-section of $\frac{1}{3}$ square inch. This, with the present form of bonding in which a hole is drilled in the rail web (or what corresponds to the web in an inverted-U contact rail), requires the hole to be somewhat less than 1 inch in diameter. Just before bonding, this hole is rimered out to 1 inch in diameter, and a ferrule forming part of the head of the bond is expanded into the hole by means of a power press, a rivet head being formed from the projecting end of the ferrule during this process. Obviously the simplest method would be to weld the head of the bond direct to the web of the rail. This could apparently be done for one bond, but for a second bond the contact of the last head with the rail web will short-circuit the arc. Apparently the only method possible is, as the authors point out, to weld cylindrical studs of the necessary diameter (probably up to 1 inch) to the web, the head of the bond being a concentric ring fitting over the stud which is expanded into and riveted over the head of the bond by a power press. There seems to be no reason why the design should not be such that with web rails the stud should be very short, thus allowing the bond and its head to go under the fish-plate, giving the shortest length of bond and protecting it by the fish-plate from theft. The studs could be welded to the rail at the rolling mills, and the doubtful point, which could be tested only by experiment, is whether the studs would be injured by the handling, carriage, delivery and stacking of the rails on the site. Exactly the same conditions apply to the track rails when bonded for use as the return circuit, except that the bonds can have smaller heads or be fewer in number. With certain classes of hard steel rails, however, it is not certain that the arc may not injure the rail as a load-carrying structure. It has been found that if the head of a track rail is accidentally struck by an arc from the electrical equipment of the rolling stock it is ruined as a track rail and must be replaced. This may not be the case if the arc affects only the web of the rail, but before the process could be applied for bonding track rails experiments would have to be carried out to see if the Cyc-Arc process of welding has any ill effects on such rails regarded as a load-carrying structure. I should be glad if the authors would say whether they consider the method referred to is the best or the only method of applying their process to the bonding of contact rails or track rails.

Messrs. L. J. Steele and **H. Martin** (*in reply*): It is interesting to get Captain Wallis-Jones's confirmation of our experience regarding the importance of satisfactory design of both the welding apparatus and supply plant, in order to be able to repeat accurately and satisfactorily welds which are effected in extremely short periods of time. We have made "Cyc-Arc" welds on to aluminium, but we are not satisfied with the mechanical strength of such welds. We expect, however, to be able to effect considerable improvement in this direction with a modified type of apparatus which has recently been brought into operation. While it is agreed that by means of the Thomson system the welding of metals having widely different melting points, such as brass and steel, can be effected, we do not consider the method and results to be as satisfactory as with "Cyc-Arc" welding, either in the simplicit and accuracy of operation, or in the quality of th welds produced. Similarly, while we are aware th surfaces of somewhat different size have been, ar can be, welded by the Thomson process, we claim th welds of such widely different sections, as can readi be made by the "Cyc-Arc" process, cannot be mad in any commercially and industrially satisfacto manner by the Thomson process.

In reply to Mr. Cowie, it is pointed out that th "Cyc-Arc" welds made at the Institution meeting f demonstration purposes were in every way satisfactor despite the fact that it was not possible to adjust ar test the welding apparatus and supply plant previo to the meeting. The reasons why improvements ha been made in the direction of the uniformity of th length of studs or tubes welded by the "Cyc-Arc process are, that not only have we now got more accura control of the time period of the arc, having eliminate certain errors which were liable to affect the accura of this period, but we have also secured better contr over the arc length upon striking and current densit resulting in greater uniformity of heat generated p weld. The average overall cost price of supplying ar fixing small studs up to $\frac{1}{2}$ inch diameter on board sh by present methods is approximately 6s. per doze The corresponding cost by "Cyc-Arc" welding shou not exceed 1s. 6d. per dozen, and may be considerab less. The cost of labour, which is a very importa factor, varies very little in "Cyc-Arc" welding betwe smaller and larger sizes of studs. Based upon th above cost prices, the economy which should result "Cyc-Arc" welding 120 000 studs of varying sizes u to $\frac{1}{2}$ inch diameter on a vessel of medium size i say, 6 months, is £2 250. The capital cost of th necessary welding apparatus and special motor-generat capable of carrying out the above-mentioned work at th specified rate is approximately £1 000.

In reply to Mr. Tate, we agree that the problem welding dissimilar metals and metals of widely differe cross-section is primarily one of temperature regulatio but this does not apply in the same sense in the "Cy Arc" as in the Thomson process. We regret that th earlier diagrams in the paper have somewhat misle Mr. Tate to assume that we use positive polarity the plate, in general, for the "Cyc-Arc" proces Unfortunately for his arguments, exactly the opposi is now the case; for although "Cyc-Arc" welds ca be made with either polarity, we are now quite co vinced that, in general, to make the stud or surfa of smaller area the positive, and the surface of th plate or larger area the negative, results in welds better allround quality. This rather upsets, not on Mr. Tate's temperature-control theories, but some our own earlier theories upon somewhat similar line Our experience on the polarity question leads us think that there will be no difficulty in alternatin current "Cyc-Arc" welding—by methods, howeve which will in no way resemble the Thomson process.

Mr. Boyce's remarks are of an explanatory natu and do not call for a reply.

In reply to Mr. Harmer, while we do not consid the "Cyc-Arc" process to be adaptable for the dire

welding of sleeves to shafts, we do think it can be used in a satisfactory manner for the attachment of such sleeves and are quite prepared to discuss proposals in this connection in detail, if so desired.

In reply to Mr. Lacey, when claiming that the "Cyc-Arc" process has provided the first solution of the problem of welding electrically, by direct means, two pieces of metal of widely different section, we should not regard the disc resistance process as coming within the scope of welding by direct means, nor do we consider this process to be applicable to extreme cases, such as that of welding small pins to massive plates or forgings, which can be readily and satisfactorily accomplished by the "Cyc-Arc" process. We agree that for certain applications a shearing action would be the most severe one to which welded studs would be subjected, and that in other cases bending would certainly be more important than tensile tests. We claim, however, that "Cyc-Arc" welds will give quite satisfactory results when subjected to either shearing or bending. The variations in current and time necessary for satisfactory "Cyc-Arc" welds do not entail very frequent adjustment in ship work, for the reason that such adjustment is, generally speaking, only necessary in welding on to plates so thin as are rarely, if ever, encountered in the hulls of, at any rate, merchant ships. On heavy plates, though slight improvement might be obtained by modification of the adjustments, such modification is not necessary to ensure quite satisfactory practical results. In welding naval brass studs to steel plates, the external indications at the weld are extremely satisfactory and reliable. Faulty welds can invariably be picked out, after a little experience, upon inspection by the operator. It is believed that the vaporization of some of the zinc in the metal at the weld to some extent accounts for the satisfactory strength of the weld. Variations in the composition of the stud, and also impurities such as may be met with commercially, undoubtedly affect the strength of the resulting weld. On this account it is recommended that studs of specified quality and purity should be used. Such studs can be supplied at practically the same cost as ordinary naval brass studs, there being no difficulty in manufacturing them. If a comparison is made between the "Cyc-Arc" welding tool and many forms of labour-saving and other devices which have to be handled at the present time, it will not be found that the "Cyc-Arc" tool is unduly heavy. No complaints whatever have been received in this direction, nor has any excessive fatigue been observed, but many have expressed surprise that the welding tool is so light and compact.

Professor Marchant appears to consider it rather unfortunate that, with the "Cyc-Arc" process, coated studs or electrodes cannot easily be used. On the other hand, we consider it advantageous that excellent "Cyc-Arc" welds can be obtained without the necessity for using coated studs or electrodes. In addition, we cannot agree that in the welding of studs by the "Cyc-Arc" process the same essential factors exist as when welding two plates by metallic arc methods. "Cyc-Arc" welding is essentially different from ordinary metallic arc welding. In the latter, the molten electrode is deposited in such a manner as to be more or less subject to oxidation and other defects, whereas with "Cyc-Arc" welding the deposited molten metal, which may be partially oxidized and contain bubbles of gas, etc., is forced out from between the faces of the stud and plate, which are joined together upon the completion of each weld. We consider this to be the main reason for the absence of oxidation in "Cyc-Arc" welds. It is preferable, though not absolutely necessary, to clean the surface of the plate before making a "Cyc-Arc" weld. We cannot agree that there is any resemblance whatever between "Cyc-Arc" and resistance welding, and we have conclusive evidence that an arc *is* struck, maintained, and extinguished in even such a short time as 0·1 second. With reference to the oscillograph records (Fig. 12), the two sets of curves shown are for different welds of the same size of stud, on account of the limitations of the oscillograph apparatus. The current curve in the lower diagram, while it cannot be accurately superimposed upon the upper curve, may be taken as an approximate indication of the current variation corresponding to the upper voltage curve. It is quite correct that the current is maintained, with an actual rise in value, for a considerable period after the arc is terminated by the return of the stud to the plate. This is an essential feature of the "Cyc-Arc" process. It is not apparent that any additional diagram is necessary beyond Fig. 7, which shows the connections of the "Cyc-Arc" welding apparatus used in taking the oscillograph records in question, the supplementary reactance, however, being short-circuited and the supply being taken, as stated, from an ordinary generator. It is agreed that the influence of reactance is not very noticeable in the oscillograph records, this being accounted for by the fact that the supplementary reactance supplied with the apparatus was short-circuited when making the welds in question. It should be noted, however, that the resistance coils in the controller are also wound inductively.

We are very much obliged to Mr. Roger Smith for his information respecting modern practice in the bonding of rail joints for electric railway traction, and also for his suggestion of a possible means of applying the "Cyc-Arc" process to facilitate such bonding. We can see no difficulty whatever in welding short brass or even copper studs (to either the track or conductor rails) of such a shape, and in such a manner, that copper bonds very similar to those now used can be satisfactorily attached to the welded studs by mechanical means. The studs can be welded either at the rolling mills, as suggested, or alternatively by means of a portable plant after the rails are laid in position. We think there is no likelihood that the welding of such studs to the webs of hard steel rails would injure them in the slightest degree, bearing in mind the very local heating effect produced at the weld. Though slight variations in the design of the welded studs and of the method of attaching the bonds to the same may be possible, we cannot make any suggestions for improvement on the general method proposed by Mr. Roger Smith. As an illustration, however, of the

variations possible in the design and arrangement as above mentioned, the welded studs may be hollow to facilitate their being expanded into the head of the bond, and also to facilitate their being welded to the rail. In conclusion, we wish to emphasize the fact that we feel sure a distinct advantage would be found in actual practice, to accrue from the welding of the stud to the rail by the "Cyc-Arc" process, as compared with the present method of ensuring contact between the rail and the bond by mechanical means

PROCEEDINGS OF THE INSTITUTION.

SPECIAL GENERAL MEETING OF CORPORATE MEMBERS AND ASSOCIATES, 17 NOVEMBER, 1921.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 5.45 p.m.

It was agreed that the notice convening the meeting should be taken as read.

The President: I wish to explain the reason for calling this meeting. Members will remember that at a Special General Meeting held on the 31st May last, the Council were requested to take the necessary steps to apply for the granting of a Royal Charter to the Institution, and, as members already know, a Charter has now been granted. At the time when the Council's application was being considered by the Privy Council, the Board of Trade made it a condition, which condition was agreed to by the Council, that so soon as practicable after the granting of the Charter all necessary steps should be taken for winding up the old Institution and the transfer of its assets and liabilities to the chartered body. The resolutions which will shortly be put to the meeting are designed to give effect to the above condition and are, in this sense, purely formal. There is no question of our solvency or insolvency, as the finances of the Institution are to-day in a very sound condition, and the resolutions merely provide the requisite machinery to enable the assets and liabilities of the old Institution to be transferred to the Institution of Electrical Engineers a incorporated by Royal Charter. I therefore move th following two resolutions:

(1) "That the Institution be wound up voluntarily and that Sir James Devonshire, K.B.E., of Electri Railway House, Westminster, S.W. 1, and Percy Fitz Patrick Rowell, of Savoy Place, Victoria Embank ment, W.C. 2, be appointed liquidators for the purpos of such winding up."

(2) "That the property of the Institution remainin after the satisfaction of all its debts and liabilities b given or transferred to the Institution of Electrica Engineers incorporated by Royal Charter date 15th August, 1921."

Mr. Ll. B. Atkinson: After what the Presiden has said it is unnecessary for me to do more tha second the resolutions.

The President: If nobody desires to ask an questions I will put the two resolutions to the meetin

The resolutions were then put and declared by th President to be carried unanimously.

The President: I now have to announce that th Confirmatory Meeting will be held on Friday, 2n December, 1921, at 5 o'clock.

The meeting then adjourned.

671ST ORDINARY MEETING, 17 NOVEMBER, 1921.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 3rd November, 1921, were taken as read, and were confirmed and signed.

Messrs. G. M. Maddock and H. W. Dipples were appointed scrutineers of the ballot for the election and transfer of members and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Members.

Horton, Francis Daniel, Capt.
im Thurn, John Knowles, Capt., R.N.
Keefe, James William.
Knox, Robert, M.D., C.M.
Whitaker, Frank Percy.

Associate Members.

Battiscombe, Henry Goodwyn.
Bayspoole, Roy Frederic H.
Berry, Edward.
Bevan, Colston Granger, B.Sc.
Bocock, William.
Boothman, Lawrence.
Carrington, Henry Carrington J.
Cranmer, John Pike.
Darby, Ben.
Dayson, Albert Ogden, M.C.
de Moura, Thomaz Custance C., B.Sc. (Eng.).
Ellis, Richard Milward.
Foster, Harold Knight.
Glen, James Baird.
Graseby, Robert Constantine.
Gravill, William Easten.
Hamilton, George Lammie
Harrop, Albert Townley.
Hitchcock, Stanley Maskell, B.Sc.
Hollis, Sydney Leonard R
Holmes, Arthur George.
Hunter, Herbert John.

Associate Members—continued.

Kos, Simon Frederick, Capt., M.C.
Lacey, Harold Morgan, B.Sc. (Eng.).
Mayall, John.
Nielsen, Herman, B.Sc.
Parsons, Richard Arthur.
Paterson, Arthur Stanley.
Phillips, Harry Howard.
Rinder, Austin Sinclair.
Robertson, William Joseph.
Robinson, Harold Edward.
Ryan, Mervyn Frederick.
St. Johnston, Thomas Anandale.
Sanford, Ernest George.
Scott, David Pyott.
Shipton, Edward.
Simister, Ernest.
Tattersall, Arthur Ewart.

Walker, David.

Graduates.

Acomb, Frank.
Aust, Octavius Leonard G.
Bedford, Reginald.
Birtwistle, Fred.
Blundell, Victor Robert.
Doubleday, George Martin.
Draper, Charles Vivian.
Firth, Charles Roy H.
Glasse, Alfred Onslow.
Goodfellow, William Muir.
Green, Ernest, M.Sc.
Howarth, Arthur W.
Kuka, Jal Mehrjibhai.
Longmore, Frederick William.
Mills, Robert Arthur.
Packe, Cyril Leslie.
Preston, Henry Reginald S.
Ranji, Maneck Jamshedji.
Seaward, Thomas Stephen G.
Sen, Akshaya Kumar.
Stenner, Edwin Joseph P.
Taylor, John Lishman.
Thompson, William Herbert.
Vitty, William Lawrence.
Wetherell, John.
Withers, Arthur Sydney.
Yardley, Harry Frederick.

Students.

Allinson, Herbert Norman, B.Sc.
Armitage, Leonard.
Armstrong, Stanley Ignatius.
Ashford, Douglas George.
Baker, Francis Louis.
Ball, Eric Theodore R.
Barlow, George Clarence.
Basil, David A.
Batra, Bodh Raj.
Bean, Henry Haffey W.
Beard, James Reginald.
Beaumont, Frederic Norman.
Bennett, Edgar Herbert.
Bibby, Robert Ernest.
Blaber, Robert William S.
Bloome, Jack.
Bradford, Percy James.
Broome, Robert Roderick.
Burney, Charles Eric.
Cavill, Richard.
Chaney, Maurice Bernal.
Chu, Kyi-Tsing.
Clark, Frederick Charles W.
Clarke, Philip Ebenezer.
Coad, Richard Harnden.
Cockburn, John Alexander
Cosgrove, Alfred Owen.
Coulthard, Stanley John.
Crabb, Leslie Samuel.
Crampton, Cecil.
Cross, Arnold Tracy.
Cunliffe, Cyril Henley.
Currah, Launcelot Edgar.
Cushny, John, B.Sc. (Eng.).
Davies, David Tudwal, B.Eng.
Davies, John.
Davies, John Neville.
Davies, Norman Charles.
de Bruyn, William.
Dilley, Albert Frederick.
Dixon, Albert Edward.
Dixon, Herbert Edward.
Dodman, Edward John.
Drake, Ronald Ivanhoe.
Dransfield, Tom.
Dutton, Gilbert Faraday.
Edwards, Leonard William C.
Elworthy, Thomas Charles.
Evans, Robert Leslie.
Ferguson, John Donald.
Finden, Harold Jack.
Gait, Francis.
Geernaert, Sidney Glorieux.
Gillespie, Alexander.
Grace, George Edward.

Students—continued.

Grant, Lachlan Colvile P. M.
Greenwood, Harry
Gripper, Henry Jasper.
Groves, Leslie Charles.
Grute, Leo Hamilton.
Haigh, James Colin.
Halliday, Victor Norman.
Harris, Cyril Edward.
Harvey, David James W.
Hawksley, Will, B.Eng.
Hazel, Henry.
Heaton, Cyril Carlyle.
Henderson, James.
Hewett, George Nele.
Hilton, Ivor Stapleton.
Hole, Percy Edward K.
Holloway, Arthur Gordon P.
Hopkins, Bernard George.
Hudson, Edwin Donald.
Huntley, Richard John.
Hurle, Robert Hampton.
Hyam, Gerald.
Jackson, Frederick Stanley.
Jackson, Harry Wilfred.
Jackson, John Clifford.
Jagger, Hubert.
James, Ralph George.
Jeffery, Frank.
Jones, Ernest William.
Jones, John William.
Jones, William Handel.
Kaye, Harry Ferdinand.
Knowles, Charles Gerald.
Laing, George Fortune.
Langley, Henry William.
Lash, Alfred Reeves.
Laverick, Wilhelmina Ethel (Miss).
Lawrence, Sydney.
Lewarn, William John.
Lloyd, David, B.Eng.
McKew, Thomas William E.
Mackintosh, Duncan Robert.
Marchand, Bernard, B.A.
Marchant, William Arthur T.
Meeks, Cecil Alfred L.
Meldahl, Helge.
Messent, Keith Santo.
Michael, Ernest Frederick.
Miller, David William.
Modak, Narhar Gopal, B.E.
Morath, George.
Morgan, Walter.
Neville, James.
Newman, Eric West.
Oura, Hector Leslie.
Owen, James McAlpine.
Patman, Reginald Horace.
Payne, Thomas Hewitt.
Peck, George Thomas.
Perman, George Hayward.
Ponday, Govind Prasad.
Poole, Stanley Livingstone.
Powell, Francis Roy B.
Priest, Charles Wilson A.
Ramsay, Kenneth Matthew A.
Raworth, Kenneth Lionel, B.A.
Ray, Charles William L.
Redshaw, Crispin Charles.
Reid, Alan Casson.
Roberts, John Hughes.
Rochester, Harry Bertram.
Rooksby, Randle Harvey.
Sach, Arthur Vincent.
Samuel, Idris Clifford.
Sansom, Leonard Edwin.
Savage, Arthur Noel.
Scott, Thomas Robertson, B.Sc. (Eng.).
Scudder, Francis Augustus.
Seymour, James Edward.
Sharma, Banwarilal.
Sharples, John Ellison.
Simpson, Alan Alfred.
Sinha, Abani Kumar.
Slater, William Thornton.
Smith, Norman Turner.
Southgate, John Cedric.
Stringfellow, Douglas.
Strode, Sidney Alfred.
Taylor, Joseph Roy.
Tomlinson, William Edwin.
Vembu, N., M.A.
Verity, Conrad Edward H.
Walton, John.
Waterhouse, Lawrence Owen.
Watson, John Frederick.
Watts, Guy Nevil.
Weir, Hugh.
Welch, Leonard John.
Wheeler, Willoughby Shaw.
White, Alec Francis.
Whiting, Henry George.
Wild, Frank.
Williamson, Robert.
Wilson, Donovan Carlyle.
Woodward, Edward Egerton M.
Wray, Francis D'Arcy.
Yates, Harold.
Yates, Joseph Henry, Jun.

Yuille, Peter Watt.

TRANSFERS.

Associate Member to Member.

Burnand, William Ernest.
Dobson, William.
Ferguson, John.
Jeffrey, Charles Stewart.
Kettle, Arthur Stafford.
Mayston, William Harry.
Mersh, Charles Melmoth B.
Peck, Henry George S.
Primrose, James Smith A.
Rodgers, Charles, O.B.E., B.Sc.
Taylor, William Henry.

Associate to Member.

Bear, Maurice Mayhew.
Dalton, William Thomas.
Loving, Arthur John C.

Graduate to Associate Member.

Ashby, Ernest William.
Ayres, George Herbert.
Brazel, Claude Hamilton.
Cooper, William Robertson.
Davies, David Reginald.
Horne, Walter.
Phillips, Reginald Mackenzie.
Pike, Frederick Andrew.
Scott, Thomas Henry I.
Smee, Alfred Thomas.
Trippe, Sidney Howard.
Watson, Robert Cecil, M.Sc.

Student to Associate Member.

Howard, Frank.
Rashid, Mohammed Abbas.
Salzmann, Otto Malcolm, B.Sc. (Eng.).
Wright, Frank.

Associate to Associate Member.

Tucker, William Sansome, D.Sc.

Student to Graduate.

Bristow, Ralph Eric.
Cronin, Bernard Augustine.
Gupta, Bahadur Singh, B.Sc.
Hayes, Leslie William.
Steel, Carlyle Stewart.
Whitehead, John.

The President : I have to announce that the Council have elected the Right Hon. Lord Southborough an Honorary Member, which is the greatest honour the Institution can confer. The Council may elect one Honorary Member per annum, and they have selected Lord Southborough for many reasons. Lord Southborough has had a very close connection with the electrical industry. Many of us know of him best as Sir Francis Hopwood, in the days when he was Permanent Secretary to the Board of Trade, in which position he had a great deal to do with the early stages of electrical enterprise. He is a member of the Privy Council; he was the British delegate to the International Railway Congresses in 1895 and in 1900; he was Vice-Chairman of the Development Commission of 1910; he is a member of the Board of Control of the National Physical Laboratory, and at the present time is a director of the Underground Railways. In most of these positions he has been able to be of very great service to engineering, and especially to electrical engineering. There is one particularly interesting fact connected with Lord Southborough that I should like to mention. He is one of the signatories of the last Report of the Board of Trade Committee on Electrical Units and Standards, and on this Report was based the Order in Council of 1894 giving legal authority for the electrical units and standards which have since been universally employed. There is probably no single piece of legislative work which has been of more importance to science and electrical engineering. Other signatories to that report were Ayrton, Carey Foster, Kelvin, Cardew, Preece, and Glazebrook. The names of the present Honorary Members of the Institution are: Elihu Thomson, Sir Joseph Thomson, Oliver Heaviside, The Hon. Sir Charles Parsons, Alexander Graham Bell, Maurice Leblanc, Arthur Kennelly, André Blondel and, now, Lord Southborough. It will be noticed that most of these are men of science, or men famous in engineering work like Sir Charles Parsons. Lord Southborough is not quite in the same category, but as this Institution grows older its base must broaden. It must get more into contact with the outside world, which, after all, has everything to do with our prosperity. I think it is of the first importance to us that Lord Southborough has this qualification, because it will very greatly assist in widening the scope of the Institution's activities. In conclusion, I think I am right in saying that Lord Southborough is the first Honorary Member who has been present when his election has been announced.

The Rt. Hon. Lord Southborough : I have the good fortune to be present upon this to me auspicious occasion, and I feel that I cannot allow the moment to pass without tendering to the Council and to all the members of the Institution my deep sense of the honour which has been conferred upon me. I know that it is the highest honour which this Chartered Institution can confer; and I am bound to say that I did not anticipate at any time in my career that the administrative side of the electrical life of this country with which I have been so long connected would have been recognized as a fitting qualification for Honorary Membership of your profession. But as you have been good enough to receive me, I should like to say that it will be my aim and object to interest myself, from the point of view which has been described by the President, in all the Institution's proceedings, and I trust that, as time goes by, I may learn something of the Institution's work and find among its members many friends.

The President announced that arrangements had been made for members to dine together at the Engineers' Club, Coventry Street, after the Ordinary Meeting to be held on the 1st December, 1921.

A paper by Mr. E. S. Byng, Member, entitled "Telephone Line Work in the United States" (see page 85), was read and discussed, and the meeting terminated at 7.55 p.m.

INDUCTION-TYPE SYNCHRONOUS MOTORS.

By Laurence H. A. Carr, M.Sc.(Tech.), Member.

(*Paper first received* 20*th January, and in final form* 6*th June,* 1921; *read at* The Institution 15*th December, before the* North-Western Centre 29*th November, before the* North Midland Centre 13*th December, and before the* South Midland Centre 14*th December,* 1921, *also before the* North-Eastern Centre 9*th January, before the* Scottish Centre 10*th January, and before the* Tees-side Sub-Centre 11*th January,* 1922.)

Summary.

The induction-type synchronous motor is a polyphase motor and has a cylindrical rotor. It is started as an induction motor of the slip-ring type and synchronizes itself when direct current is switched into the rotor.

The characteristics and construction of this type of motor are compared with those of other polyphase motors.

The self-synchronizing feature of this type of machine is discussed in detail so as to present a full physical conception of the phenomena which occur, and the subject is illustrated by means of oscillograms.

A mathematical expression is deduced for the limiting conditions beyond which synchronizing is uncertain.

The considerations which determine the selection of the excitation voltage are discussed, as well as the method of control and other practical points affecting the installation of these machines.

Introduction.

The correction of the power factor of a system, or a portion of a system, to a value approaching unity, has attracted the attention of central station engineers for many years. The importance of this subject is so well realized that it is probably unnecessary to labour the point, but, owing to the high capital costs now involved, it is more than ever necessary to utilize existing cables to the fullest extent by making them carry a current as nearly as possible in phase with the pressure. The induction-type synchronous motor, or synchronous induction motor as it is frequently termed, has been developed to produce a motor which, while retaining the advantages of a synchronous motor as regards its property of power-factor correction, possesses the good starting characteristics of the slip-ring induction motor.

Theory.

The synchronous induction motor consists essentially of an induction motor coupled to a direct-current exciter. It is started up as an induction motor and, when the exciting current is switched on, it synchronizes itself and then continues to run as a synchronous machine.

The difference between the duty of the rotor when the machine operates as an induction motor and when it operates as a synchronous machine may be described in the following manner. In either case, since torque is produced through the interaction of flux and current, and since the torque acts on both stator and rotor (though in different directions), both stator and rotor must carry currents proportional to the torque; these currents may be termed "power currents." In addition, a magnetizing current producing flux must be carried by either the stator or the rotor, or in part by both.

In the induction motor the secondary carries power current only. Being produced by induction, this current automatically increases with load and so, within limits, provides for a certain overload capacity.

In the synchronous motor the secondary may carry, in addition to the "power current," a part or the whole of the magnetizing current, and possibly even an over-magnetizing current which will give a leading component to the primary current.

The secondary current in this case, however, is controlled by external means, and does not increase automatically when an overload is applied.

Hence the normal full-load excitation of a synchronous machine must be large enough to allow for a reasonable overload capacity. This may be done in either of two ways.

The economical method is to run the motor normally at a leading power factor of about 0·9, and thus utilize the extra excitation to correct the power factor of other parts of the system.

The uneconomical method is to increase the air-gap of the machine and waste the excitation by using it to drive the flux through this increased air-gap. This method has a further disadvantage in a synchronous induction motor, in that it impairs the performance of the machine as an induction motor during the starting period, since it increases the necessary magnetizing current drawn from the line.

It is clear from the foregoing that in the majority of cases there will be little difference in first cost between a synchronous induction motor arranged for unity power factor and one arranged for 0·9 leading power factor, since, in order to allow for the necessary overload capacity, the same exciting member has to be used in each case.

Comparison with Other Types of Machines.

The principal advantage which the synchronous induction motor possesses over the plain synchronous motor lies in its starting characteristic. It is well known that the synchronous motor with damper windings for starting will only start against some 40 to 50 per cent of full-load torque, and even then requires a large current at a low power factor for an appreciable time, whereas the synchronous induction motor starts up from rest like an induction motor and easily synchronizes itself almost instantaneously against full load or more than full load.

Compared with the corrected induction motor, i.e.

the induction motor fitted with a phase advancer or vibrator, the synchronous induction motor possesses the following advantages: —

(*a*) The synchronous induction motor may be corrected not merely to unity power factor, which is about the economical limit of power-factor correction for an induction motor with phase advancer, but to a leading power factor, for which, as has been shown above, it is even more suitable than for unity power factor.

(*b*) The synchronous induction motor delivers a leading component of current down to no load; in fact, this component increases slightly as the load decreases, whereas with a corrected induction motor the power factor lags as the load decreases, until at no load the corrected induction motor takes as much lagging current as a plain induction motor.

(*c*) The action of a phase advancer is to increase the slip. The synchronous induction motor, on the other hand, runs at constant speed; it has zero slip.

(*d*) The commutator, which it appears must be introduced into all machines that act as correctors of power factor, commutates low-voltage direct current in the case of the synchronous induction motor, instead of alternating current in the case of the phase advancer or vibrator.

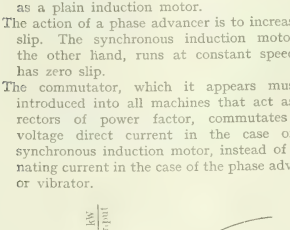


FIG. 1.—Current vector diagrams for alternating-current motors.

Fig. 1 represents the current vector diagrams for the following types of motors:—

Curve A: Synchronous induction motor, 0·9 leading power factor at full load.
Curve B: Synchronous induction motor, 1·0 power factor at full load.
Curve C: Corrected induction motor, 1·0 power factor at full load.
Curve D: Plain induction motor.

The relative phase angles at various loads are clearly shown by this diagram, and, if the diagram be turned in a clockwise direction through a right angle, it shows even more clearly the relation between the reactive kilovolt-amperes—leading or lagging as the case may be—and the input kilowatts for the various machines considered.

The superiority of the synchronous induction motor with leading power factor for power-factor correction is obvious from this diagram.

Construction.

Two slightly different types of synchronous induction motor are at present manufactured in this country, but in both the stator is a standard induction-motor stator, with semi-closed slots, and either concentric or diamond winding.

In the one type the rotor is always of the three-phase type with a barrel winding made up of diamond-shaped coils. This winding may consist of two or four bars per slot in semi-closed slots, but in many cases, in order to arrange for a higher excitation voltage, the rotor is wound with diamond coils each containing several turns of rectangular wire, and in this case the slots are of the fully open type, in order to facilitate winding.

Although when excited by direct current one phase carries twice as much current as either of the other two, it is usual to make all the conductors of the same size. When running synchronously this three-phase winding has an exceedingly good damping effect.

In the other type, the main rotor winding consists of concentric coils of flat copper ribbon wound in open slots, covering about two-thirds of the rotor periphery. This is frequently the only winding, the rotor thus being single phase (in which case the centre of the pole is left unslotted). Occasionally the remaining third of the rotor periphery is wound with a second phase of reduced cross-section for starting, this winding being short-circuited to act as a damper winding when the machine is running at full speed. In both types each motor has its own exciter which is driven either direct or, in the case of a low-speed motor, by gearing or chain, so as to give a higher speed and enable a smaller exciter to be used.

Starting and Synchronizing.

The starting of synchronous induction motors presents no difficulty either in theory or in practice, since, in common with other wound-rotor induction motors, they start up with a resistance in the rotor circuit and are capable of accelerating against from 2 to $2\frac{1}{2}$ times full-load torque.

The self-synchronizing feature of these machines is their only unusual characteristic, and it is important that the large torque which they can exert while synchronizing should be fully realized. In order that this operation may be clearly understood it is necessary to describe it in some detail. After the machine has attained its full induction-motor speed with all external resistance in the rotor circuit short-circuited, then, in order to synchronize, the rotor circuit is momentarily opened and closed again so as to include the exciter in circuit. For a short period after this switch is closed the rotor carries both the induced alternating current and the forced direct current. The final action of these two currents is to cause the machine automatically to accelerate still further, and in normal operation synchronous speed is reached in a fraction of a second.

the machine then settling down to run as a normal synchronous motor.

The principles underlying this operation may be more easily followed if the case where the machine is unable for some reason or other to synchronize itself be first considered.

When direct current is switched on to the rotor the machine will develop a torque as a synchronous machine,

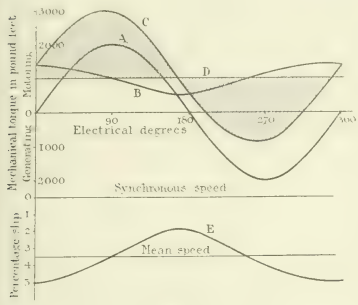


Fig. 2.

and as the rotor slips back through a pole-pitch (relatively to the synchronously rotating field) this torque is alternately motoring and generating and thus causes a fluctuation in speed. Since the machine is running below synchronous speed there will exist in the rotor, superposed on the direct current, an induced alternating current which will vary not only with time but with the speed of the rotor. This current will produce a varying torque which must be added to the synchronous torque to obtain the total torque. The torques acting on the rotor as it moves back relatively to the synchronous field are shown in Fig. 2. The constants

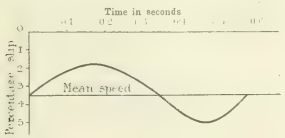


Fig. 3.

from which these curves were derived graphically are given in the Appendix.

With a cylindrical rotor, neglecting minor corrections, the synchronous torque is represented by a sine wave (curve A) The fluctuating induction torque is represented by curve B, and the sum of curves A and B gives the total motoring torque C. If the load torque D, which is constant, is plotted above the datum line instead of below it, the difference between curves C and D shown cross-hatched in Fig. 2 gives the torque causing acceleration and deceleration of the moving masses. The variation in speed produced by this torque is shown by curve E, which also represents the slip, to which the induction torque is proportional. The mean speed is seen to occur when the synchronous torque is a maximum, so that only one-half of the positive lobe of the torque curve is available for acceleration above the mean speed. Since the speed is not constant the angle swept out is not proportional to time, and the areas of the torque curves in Fig. 2 are not proportional to the work done. In Fig. 3 the same speed curve is transferred to a time basis.

The actual stator and rotor currents of a machine which failed to synchronize are shown in Fig. 4, which is drawn from an oscillogram obtained with such a resistance in the rotor circuit that the slip was too great to permit the synchronization of the machine.

It is clear that, if the machine is to synchronize,

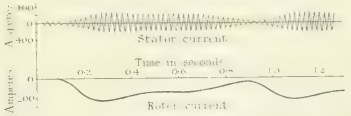


Fig. 4.—Stator and rotor currents in the case of a machine which failed to synchronize.

the oscillation must be large enough to allow the rotor to swing right up to synchronous speed.

The position of the rotor relative to the synchronous field at the moment of switching on the excitation has

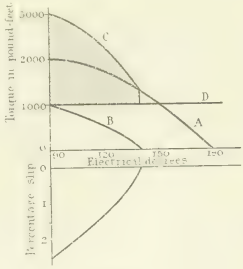


Fig. 5.

an influence on the commencement of the oscillation and, if the load is within the synchronizing limit, on the exact sequence of the synchronizing phenomena.

It is clear that if the switch is closed at a position on the torque curve in Fig. 2 corresponding to a speed lower than the mean speed, the first upward swing will reach a higher speed than the normal oscillation, and hence synchronization is easier and will occur earlier. If, on the other hand, the switch is closed at

a torque corresponding to a speed above the mean speed, the first downward swing will be larger. In this case the mean speed will gradually rise, due to the induction-motor torque, until it reaches the original induction-motor speed, so that the worst case to be considered in practice is that in which the mean speed is passed through when the synchronous motoring torque is a maximum. If the machine will synchronize under these conditions it will always synchronize. Consequently this moment of switching on the excitation (assuming that it rises instantaneously to its full

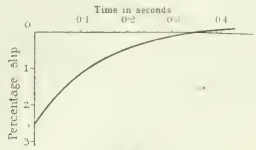


FIG. 6.

value) has been adopted throughout the paper in the calculated examples.

In order to increase the maximum speed of the rotor when oscillating under the influence of the two torques, two methods may be adopted. Either the mean speed can be raised by reducing the rotor resistance or by reducing the load, or the amplitude of the oscillation may be increased by increasing the synchronizing torque or reducing the inertia of the moving masses. Fig. 5 is calculated for a motor having the same

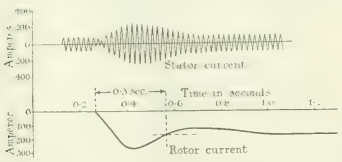


FIG. 7.—Stator and rotor currents in the case of a machine which synchronized itself.

constants as those used for Fig. 2, except that the rotor resistance is lower, giving a slip of $2\frac{1}{2}$ per cent at full load as an induction motor. This curve shows that the machine reaches synchronous speed when the angle of lag between the centre of the rotor pole-face and the centre of the synchronously rotating flux wave is greater than 90 electrical degrees. In the steady condition of running as a synchronous motor, however, this angle of lag is less than 90 electrical degrees.

The rotor will therefore, due to the excess of synchronous torque over load torque, accelerate still further and creep forward to its stable position, where synchronous torque is equal to load torque, at which it will finally settle after a slight oscillation. This is also indicated by the corresponding speed/time curve in Fig. 6, where at synchronism the speed is seen to be still rising.

During this creeping forward of the rotor the slip is negative, and hence there will exist in the rotor a small induced current in the reverse direction to that which existed during the actual period of synchronization. This is clearly shown in Fig. 7, which was obtained from an oscillogram taken while a machine synchronized itself. Fig. 8 shows a similar oscillogram of the rotor current of a machine which was switched in at an unfavourable moment and which did not synchronize until the second swing, the fourth half-wave on the record corresponding to the negative slip as the rotor moved forward to take up its final position. This forward movement of the rotor can easily be seen on test by stroboscopic methods.

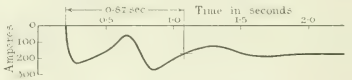


FIG. 8.—Oscillogram of rotor current.

The variation in stator current is shown on the oscillogram in Fig. 7. At the commencement of the record the stator current is the magnetizing current drawn from the line while the rotor circuit is momentarily interrupted. The temporary rise in, and also the final steady value of, the stator current are shown.

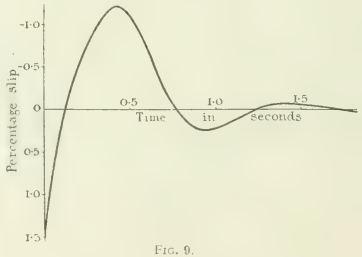


FIG. 9.

It is seen from this record that there is no serious kick or disturbance on the line, the maximum current being not more than about twice the full-load current, and persisting, in the case of successful synchronization, for merely a fraction of a second.

In order to obtain these records, an external resistance was inserted in the rotor circuit to make the conditions of synchronization more difficult, and, in practice, with normal slips, it is exceedingly rare for a machine to fail to synchronize on the first upward swing, particularly as, owing to the low resistance of the rotor necessary to carry the exciting current, the slip as an induction motor is very low, usually about 1 per cent. The conditions obtaining in practice may be more nearly represented if a still lower slip be taken for the example used for Figs. 2, 3, 5 and 6.

Fig. 9 shows the speed curve if the initial slip is $1\frac{1}{2}$ per cent, which is still high, although with this value there is a considerable margin in synchronizing power. This curve is prolonged to show the oscillation which takes place after the synchronous speed is reached, and also shows how quickly this oscillation dies down.

The corresponding variation in the value of induction-motor torque as the angle of pole-lag changes is shown in Fig. 10 under the synchronous-torque sine curve. A scale of time in seconds is marked along the curve of induction torque.

Limit of Synchronization.

The critical case in which the machine will only just synchronize is of importance, since this gives

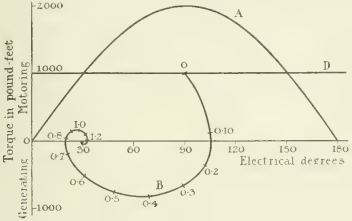


Fig. 10.—Variation of induction-motor torque with angle of pole-lag.

The figures along the curve of induction torque refer to time in seconds.

the limiting conditions under which synchronization can be guaranteed. This is represented in Figs. 11 and 12 and it is obvious that the curve of speed

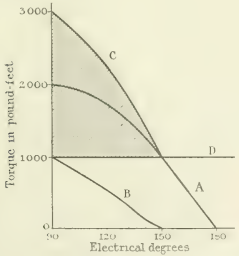


Fig. 11.

is asymptotic to the synchronous speed, the machine synchronizing after an infinite time with a pole-lag such that the synchronous torque is just equal to the load torque.

The following mathematical expression for the conditions which correspond to the critical case is developed in the Appendix:

$$\omega = \sqrt{1 \cdot 2 \phi T_m / \mathbf{I}}$$

where ω is the limiting slip in mechanical radians per second;

T_m is the maximum torque in pound-feet exerted as a synchronous motor with the excitation considered, that is, T_m is the torque corresponding to the maximum "synchronous kilowatts";

$\mathbf{I}$ is the moment of inertia Wr^2/g in pounds, feet, and seconds;

ϕ is the mechanical angle of lag of the rotor pole from the maximum-torque position, measured in radians, when it is exerting a torque equal to T_l, i.e.

$$\phi = (1/p) \text{ arc cos } (T_l/T_m)$$

where p is the number of pairs of poles and T_l is the steady load torque in pound-feet.

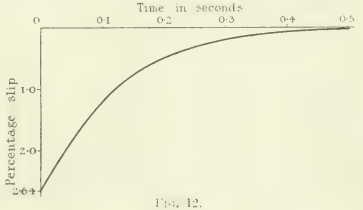


Fig. 12.

The shape of the resulting curve when ω is plotted against horse-power is shown in Fig. 13 for full-load excitation for one particular case, namely, that for which the performance curves are shown in Fig. 14. In this curve the total stored energy of the mechanical masses is assumed to be six times that of the motor itself. The variation of slip with load for the same machine running as an induction motor is also shown in Fig. 13.

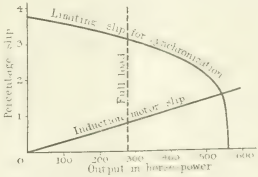


Fig. 13.—Synchronizing limit of 280-h.p. motor.

The results of tests appear to show that the limiting slip calculated from the formula given above agrees well with the actual result obtained in practice. Owing to the effect of the position angle of the rotor relative to the flux at the instant of switching on the excita-

tion, the exact figure of limiting slip is difficult to obtain with a high degree of accuracy on test, but, by raising the excitation gradually instead of applying it suddenly, errors due to this cause can to a large extent be minimized.

The following table gives a series of such tests at various voltages and excitations:

Primary Terminal Voltage	Load	Frequency	Exciting Current	Index T/T	Limiting Slip	
					Calculated	Tested
volts	kW	cycles	amps.		%	%
498	36·4	43·8	185	0·314	3·08	3·04
468	31·3	45·9	180	0·292	2·80	3·05
462	32·5	45·9	180	0·309	2·75	3·05
435	26·7	45·8	150	0·324	2·43	2·70

In all the above cases a permanent resistance was used in the rotor circuit to increase the normal slip

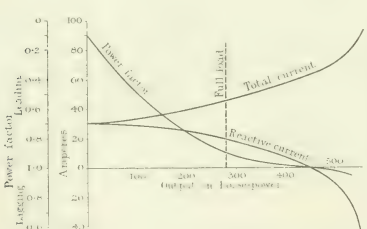


Fig. 14. Performance curves of a 3,300 volt, three-phase, 50 cycle 280-h.p. synchronous induction motor.

of the machine. Without this resistance, and with a slip of 1·06 per cent, it was found on test that the machine would synchronize under similar conditions against a load of 96 per cent of its maximum synchronous torque, the corresponding figure calculated by means of the above formula being 98 per cent.

Peculiarities of Single-phase Rotors.

Owing to increased leakage, a single-phase rotor in an induction motor gives rather less starting torque than is obtained with a three-phase rotor. In addition, the single-phase rotor has the disadvantage of a marked drop in torque at one-half synchronous speed, and, if the rotor starting resistance is cut out too rapidly, so that there is little resistance in the rotor circuit by the time the machine has attained this speed, it will "crawl" or "hang" at half speed. A full description of this phenomenon is given by Arnold and La Cour.* Should this occur in practice it is only necessary to switch in again some of the starting resistance, when the machine will pick up speed once more. The possibility of the machine behaving in this manner can be largely reduced by the use of a slow-motion starter.

* "Die Wechselstrommaschine," vol. 2; "The Induction Machine," p. 186.

Overloads.

As a synchronous machine, the synchronous induction motor can be arranged for any desired pull-out torque, the most economical figure being from 75 to 100 per cent overload for a machine having a leading power factor of 0·9, and correspondingly higher figures for a machine having a power factor of 0·8 or 0·85. Since the maximum torque of an induction motor is generally greater than the pull-out torque of a synchronous motor, if the machine falls out of synchronism it will usually continue to run as an induction motor with the fluctuation in speed already described, and in this case, when the load is reduced, the machine will again pull itself into step automatically. It is not, however, recommended that this extra overload capacity should be made use of in any but emergency conditions, owing to the fluctuating nature of the torque developed. The pull-out torque when the machine is running as a synchronous motor may, however, be increased if a large temporary overload has to be carried, by increasing the excitation above the normal value.

Operation.

The vector diagram of the synchronous induction motor has already been referred to in Fig. 1. The total current, reactive current, and power factor for a machine having a leading power factor of 0·9 with 100 per cent overload capacity, are plotted in Fig. 14. In this case the base line is taken as horse-power output, not input as in the case of Fig. 1. The effect of increased excitation is simply to compress both the load and current scales, so that with 25 per cent increased excitation the power factor will be 0·9 at 25 per cent overload, and the maximum load will be $2\frac{1}{2}$ times full load.

Reliability.

Since the set consists simply of an induction motor and exciter, the reliability need not be questioned. The argument put forward in support of phase advancers, that should any breakdown occur in the exciting circuit the main motor can still be run as a plain induction motor, holds equally good with the synchronous induction motor.

Excitation Voltage.

It is necessary on synchronous induction motors to keep the excitation voltage low, since, if the number of turns on the secondary winding be increased so as to require a higher excitation voltage, the induced pressure in the secondary at starting is also increased.

The relationships between the excitation voltage, excitation current, and the open-circuit voltage of the secondary at standstill follow certain natural laws which are beyond the control of the designer. These laws are developed in the Appendix and lead to the following results:—

Let E_2 = excitation voltage;
I_2 = excitation current;
V = secondary open-circuit voltage;
P = input to machine at full load, in kW;
λ = percentage which secondary losses bear to input at full load;
γ = overload capacity in terms of full load.

Then $E_2 = 0{\cdot}0122V\lambda/\gamma$ for a star-wound or single-phase secondary;
and $E_2 = 0{\cdot}0141V\lambda/\gamma$ for a mesh-wound secondary.

The corresponding equations for the exciting current become:—

$I_2 = 820\gamma P/V$ for a star-wound or single-phase secondary; and
$I_2 = 708\gamma P/V$ for a mesh-wound secondary.

Thus, with a secondary loss of 3 per cent, an overload capacity of twice full load, and a limiting starting voltage of 2 000 (the figure usually adopted for large machines), the excitation voltage will be 36·6 for a star or single-phase secondary, and 42·3 for a mesh-wound secondary. With larger machines the ratio of excitation volts to excitation amperes becomes unduly low, and it is usual to arrange the secondary winding in two circuits, which are connected in series for excitation purposes. This doubles the excitation voltage and halves the excitation current.

In this case with polyphase windings it is usual to leave the two secondary windings independent during the starting period, using only one of the circuits for starting. This method simplifies the switchgear. Since the value of the secondary current when the machine acts as an induction motor is only about one-half that of the exciting current when running synchronously, it is perfectly safe to run the machine continuously as an induction motor with only one secondary winding short-circuited. With the two-circuit arrangement, additional slip-rings are required where the secondary winding is on the rotor. Five slip-rings are necessary for a double mesh winding, independent at starting, and six for a double star winding. Four slip-rings are required for a double single-phase winding, and in this case the windings are usually connected in parallel for starting and are not left independent. Similar arrangements may be adopted on smaller motors, and the starting voltage reduced to 1 500 or 1 000.

Control and Switchgear.

Each synchronous induction motor is provided with its own exciter. This practice should be adhered to, as it makes each set self-contained and more fool-proof than if a separate source of excitation were used.

Fig. 15 shows in skeleton form the most usual arrangements of the switch and control gear for various

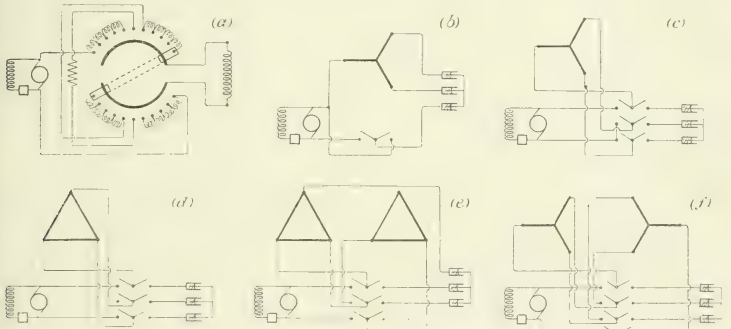


Fig. 15.—Switch and starter connections.

alternative types of secondary winding. In all cases the sequence of operations is as follows:—

(1) The main switch is closed.
(2) The rotor starting resistance is gradually cut out and short-circuited.
(3) The rotor circuit is momentarily interrupted.
(4) The rotor circuit is closed on the exciter.
(5) The exciting current is adjusted, if necessary, to give the desired leading power factor.

A single switch [Fig. 15 (*a*)] for single-phase rotors has been developed by one manufacturer to carry out in the correct sequence all the operations necessary after closing the main switch. This method of control has the disadvantage that synchronization is attempted with all resistance in the rotor circuit, i.e. with a very weak synchronizing field.

In the case of three-phase rotors it is usual to employ switchgear built up of standard apparatus consisting

essentially of a liquid starter, and sheet-iron panels containing the rotor change-over switch, exciter shunt regulator, main switch, etc.

Fig. 15 (*b*) represents the arrangement sometimes adopted for small machines where the starting voltage can be limited to 1 000. Here a single-pole change-over switch is sufficient, and it will be noticed that the exciting current passes continuously through the short-circuiting contacts of the liquid starter, which must be made suitable for carrying it.

Fig. 15 (*c*) is the standard arrangement for star-wound rotors, and in this case a 3-pole change-over switch is used, thus entirely isolating the exciter during the starting period, and the liquid starter during the running period.

Fig. 15 (*d*) is similar, but is for use with mesh-connected rotors.

Figs. 15 (*e*) and 15 (*f*) show arrangements for double-circuit rotors, mesh and star respectively, where only one circuit is used for starting, but both circuits are used in series for direct-current excitation.

It is standard practice to fit interlocks on both starter and change-over switch so that the main switch cannot be closed unless these are in the starting position, but these refinements have been omitted in Fig. 15 for the sake of clearness.

Automatic starting by means of contactors has been successfully applied to the synchronous induction motor, additional contactors for synchronizing being the only fundamental difference between such starters for synchronous induction motors and those for plain induction motors.

"Inverted" Machines.

It is quite possible theoretically to make an "inverted" machine, that is to say, to connect the supply to the rotor and use the stator as a secondary or exciting member. This has the advantage that the high-tension secondary voltage induced at starting is produced on the stationary and not on the rotating element. Further advantages are the greater amount of space on the stator for the exciting winding, and the possibility of series-paralleling the secondary winding at the start without the complication and expense of extra slip-rings. This type of construction has already been applied to several machines, and it appears probable that in the future this practice will be extended, particularly in connection with large machines for low-tension supply.

Efficiency.

The efficiency of the synchronous induction motor with a leading power factor of 0·9 is usually a little below that of the plain induction motor. As a rule the difference is not more than 1 per cent. The increased losses are due to the extra excitation necessary to give the required overload capacity, although this increase is partly offset by the reduced stator loss when the power factor is higher than that of the induction motor.

There is frequently a further reduction in losses due to the observed fact that the core loss of a synchronous induction motor when running synchronously is less than that of the same machine when running as an induction motor. This, however, has been proved only in the case of motors with three-phase rotors, and probably does not hold good for single-phase or two-phase rotors.

Price.

It is impossible to state a hard-and-fast rule for the difference in price between the plain induction motor and the synchronous induction motor, as this depends on so many different conditions, but it may be said that the price of a synchronous induction motor having a power factor of 0·9 is about 25 to 40 per cent higher than that of a plain induction motor, all accessories, i.e. switchgear, exciter, etc., being included. This figure would, however, probably be considerably exceeded in the case of machines below 100 h.p.

The following comparison may be made between a synchronous induction motor at 0·9 leading power factor and an induction motor at 0·9 lagging power factor: The induction motor takes a magnetizing component of 48·5 kVA per 100 kW input, while the synchronous induction motor gives out a magnetizing component of 48·5 kVA, that is, the advantage of the latter over the former is 97 reactive kVA. To obtain this, the first cost of the machine is increased some 33 per cent, or, roughly, the capital cost per leading kilovolt-ampere is one-third of the capital cost per kilowatt, while, since the extra loss is only 1 per cent, the apparent efficiency of the leading component is of the order of 99 per cent.

Suitability.

On account of the power-factor-correcting duty of the synchronous induction motor, it is most suitable for use in connection with drives where it will be required to run continuously, when, although the load may be varying, the power-factor correction still continues. Many machines of this type have been built in this country during the past few years and have been successfully applied to a number of different duties. The drives most favoured by operating engineers appear to be compressors, fans, and pumps, for which these motors are most eminently suitable, and the majority of machines hitherto built are probably included in this group. At the same time they have also been applied to a number of miscellaneous duties, e.g. driving generators, line shafts, etc.

Size.

Below 50 or 60 h.p. the relatively small amount of leading kilovolt-amperes obtained and the increasing relative cost of the synchronous induction machine render it less popular. The real field for these machines may be said to be from 100 h.p. upwards. The size to which they can be built appears to be practically unlimited, although the largest that has, up to the present, been built in this country is, to the best of the author's knowledge, 1 125 h.p.

In conclusion, the author wishes to thank the Metropolitan-Vickers Electrical Company, Ltd., for permission to publish certain information, particularly the oscillograms shown in Figs. 4, 7 and 8, together with the table of synchronizing tests.

APPENDIX.

Derivation of Formulæ for Excitation Voltage and Current.

Let E_2 = excitation voltage;
I_2 = excitation current;
V = secondary open-circuit voltage;
P = input to machine at full load, in kW;
λ = percentage which secondary losses bear to the input at full load, that is, $\lambda = 100\ E_2 I_2 \div (1\,000\ P)$;
γ = overload capacity in terms of full load.

With a three-phase star-connected secondary the primary winding may be assumed to be replaced by an equivalent winding having the same number of turns as the secondary winding. In this case, neglecting leakage, the primary electromotive force will have the value V.

Let I_w be the power component of the primary current corresponding to this voltage at full load. Then at the pull-out point, since, neglecting minor corrections, the number of primary ampere-turns in phase with the voltage is equal to the number of secondary ampere-turns,

$2I_2$ (turns per phase) $= 2{\cdot}828 I_w \gamma$ (turns per phase)

or $I_2 = 1{\cdot}414 I_w \gamma$
but $I_w = 1\,000\ P/(\sqrt{3}\,V)$
hence $I_2 = 820 \gamma P/V$
Also, since $E_2 = 1\,000\ P\lambda/(100\ I_2)$
$E_2 = 0{\cdot}0122\ V\lambda/\gamma$

The proofs for single-phase and mesh-wound secondaries may be developed in a similar manner.

Derivation of Formula for Limiting Slip for Synchronizing.

Let T_m = maximum synchronous torque, in pound-feet;
T_l = load torque, in pound-feet;
$\mathbf{I} = Wr^2/g$ in pounds, feet, and seconds;
p = number of pairs of poles;
α = angle of lag of centre of pole of rotor behind position of maximum synchronous torque, in mechanical radians;
t = time in seconds;
ω = initial slip in mechanical radians per second, which is the slip corresponding to an induction-motor torque of T_l;
(*Note*: $\omega = d\alpha/dt$ at $t = 0$)
ϕ = angle in mechanical radians between the rotor position corresponding to a synchronous torque of T_m, and that corresponding to a torque of T_l;
$\phi = (1/p)$ arc $\cos(T_l/T_m)$.

Since torques are measured as positive when acting forwards, and angles of lag are measured backwards:—

Torque = − (Moment of inertia × acceleration)

The various torques present are:—

$$\text{Synchronous torque} = T_m \cos p\alpha$$

$$\text{Induction torque} = \frac{T_l}{\omega}\cdot\frac{d\alpha}{dt}$$

$$\text{Load torque} = -T_l$$

Hence the full expression for movement relative to synchronism becomes

$$T_m \cos p\alpha - \frac{T_l}{\omega}\cdot\frac{d\alpha}{dt} - T_l = -\mathbf{I}\frac{d^2\alpha}{dt^2}$$

This cannot be solved by the usual mathematical methods, and can only be conveniently dealt with graphically. The curves of torque and speed variation have been calculated from the above expression by graphical step-by-step methods for an imaginary motor representing an average machine with a heavy flywheel load. The constants selected for the example were: Periodicity = 50; speed = 600 r.p.m.; $T_m = 2\,000$; $T_l = 1\,000$; $\mathbf{I} = 180$; which represent in round figures a 110-h.p. motor with a total stored energy of some 10 times the stored energy of the machine itself starting against full load. An adjustable rotor resistance has been imagined, arranged so as to give, at full load, slips of $3\frac{1}{2}$, $2\frac{1}{2}$, $1\frac{1}{2}$ and 2·64 per cent respectively for the curves in Figs. 2, 5, 9 and 11.

Since, after reaching synchronous speed for the second time, the oscillation is small and the synchronous torque varies almost directly as the angle of lag, the ordinary equation for a damped oscillation has been used for calculating the remainder of Figs. 12 and 13, the exact figures being:

$$d\alpha/dt = 0{\cdot}286 e^{-2{\cdot}94t} \sin 6{\cdot}66t$$

where t is counted from the second point of passing through synchronous speed. These values were then transferred to percentage slips. The solution of the relationships between the various constants is obtained from consideration of the curve of total accelerating torque in Fig. 11.

It is clear from this diagram that the average torque is greater than it would be if it followed a straight-line law. The method adopted has been to assume that the torque follows a straight-line law (which is capable of easy mathematical treatment) and to apply a correction factor to the solution thus found.

The straight-line law would give the equation

$$-\mathbf{I}\frac{d^2\alpha}{dt^2} = T_m\left(\phi - \alpha\right)$$

since at $\alpha = 0$ the load torque is equal and opposite to the induction torque.

The solution of this is

$$\alpha = \phi\left(1 - \epsilon^{-1{\cdot}47t}\cos 1{\cdot}47t\right)$$

and $$\frac{d\alpha}{dt} = \sqrt{\left(\frac{\phi T_m}{\mathbf{I}}\right)}\epsilon^{-1{\cdot}47t}\sin 1{\cdot}47t$$

Therefore, when $t = 0$,

$$\frac{d\alpha}{dt} = \omega = \sqrt{\left(\frac{\phi T_m}{\mathbf{I}}\right)}$$

In the actual case considered, however, the average torque is about 1·2 times the straight-line torque, hence the final result is reached:

$$\omega = \sqrt{\left(\frac{1{\cdot}2\phi T_m}{\mathbf{I}}\right)}$$

which agrees very closely with results obtained by the step-by-step method.

BIBLIOGRAPHY.

English.

AYRES, W. E. M.: "Power Factor Improvement by Induction Synchronous Motors," *British Westinghouse Co. Co.*, 1918, vol. 3, p. 177.

EARDLEY-WILMOTT, G. H.: "Phase Compensation," *Electrician*, 1914, vol. 73, p. 51.

HUNT, L. J.: "The Single-Field Cascade Machine," *Proceedings of the South Wales Institute of Engineers*, 1919, vol. 35, p. 309.

KAPP, G.: "On Phase-Advancing," *Journal I.E.E.*, 1913, vol. 51, p. 243.

ROSENBERG, E.: "Self-Synchronizing Machines," *ibid.*, p. 62.

WOOD, A. P.: "Some New Flywheel Storage Systems," *ibid.*, 1907, vol. 39, p. 414.

"Electrical Equipment of a Dundee Shipyard," *Electrician*, 1920, vol. 85, p. 278.

"Self-Starting Synchronous Motors," *Engineer*, 1913, vol. 115, p. 90.

American.

KOSAKO, J. K.: "Self-exciting Synchronous Motor," *Electrical World*, 1920, vol. 75, p. 723.

STEINMETZ, C. P.: "Theory and Calculation of Electrical Apparatus," 1st edn., 1917, p. 57.

WARNER and KNOWLTON: "Improving Power Factor Conditions with Induction Motors," *Electrical World*, 1920, vol. 76, p. 1021.

"Self-Starting Synchronous Motors," *ibid.*, 1913, vol. 61, p. 791.

Correspondence in the *Electrical World*, 1921, vol. 77, pp. 204 and 936.

French.

GENKIN, V.: "Synchronized Induction Motor," *Revue Générale de l'Electricité*, 1921, vol. 10, p. 187.

LE MONNIER, J.: "A New Type of Electrical Motor for Polyphase Circuits," *ibid.*, 1920, vol. 8, p. 687.

SOULIER, A.: "Power Factor Improvement," *ibid.*, 1919, vol. 5, pp. 505 and 831.

Correspondence, *ibid.*, 1921, vol. 9, p. 201.

"The Oerlikon Synchronous Induction Motor," *Le Génie Civil*, 1921, vol. 79, p. 150.

Miscellaneous.

GLWTCKI, J.: "A Synchronous Motor for Asynchronous Starting Under Load," *Elektrotechnische Zeitschrift*, 1921, vol. 42, p. 1217.

"A Synchronous Induction Motor," *Schweizerische Bauzeitung*, 1921, vol. 78, p. 8.

The following articles dealing with the synchronization of salient-pole machines may be studied with advantage:—

HAY, A., and MOWDAWALLA, F. N.: "Starting Conditions of Synchronous Machines," *Journal of the American Institute of Electrical Engineers*, 1920, vol. 39, p. 34.

SHAND, E. B.: "Starting Characteristics of Synchronous Motors," *Electric Journal*, 1921, vol. 18, p. 309.

Discussion at The Institution, 15 December, 1921.

Dr. S. P. Smith: I am not quite sure whether it is on account of the large starting torque which can be obtained from the slip-ring rotor, or on account of the high power factor, that the induction-type synchronous machine is the more important. If it is the latter, then possibly the various forms of the salient-pole synchronous motors have many advantages. In connection with the induction type of machine there are certain disadvantages which make the salient-pole construction appear to be superior in some ways, and obviously much will depend on whether it is really the high power factor or the high starting torque that is needed. The slides which the author has shown prove that the induction type is now being built very extensively. We have not, however, got rid of the fundamental disadvantages of the induction motor itself It is true that sound mechanical design has helped us to overcome these disadvantages, but the small air-gap has not been removed, and I am afraid I do not agree with the author in regard to the wasteful expenditure of ampere-turns in driving flux through a long air-gap. I think it is much better to have a long air-gap, and expend possibly somewhat more energy in field losses, because of the larger number of ampere-turns required, than it is to have the shorter gap in the induction motor type. This is one of the points which will influence the relative advantages of this machine in the future. Of all the criticisms against this type of machine I think the low-voltage commutator is really the chief. It is possible, as the author points out, to help matters by using a series-parallel arrangement, but the fact remains that the rotor of an induction motor is inherently a winding with a fairly low resistance, and the exciter cannot be so satisfactorily designed as for the synchronous motor. The large slip-rings, large currents, and low voltage connected with the direct-current excitation will, I think, probably tell against the machine more than anything else. It is certainly a disadvantage to have a large induction motor of the slip-ring type in which the slip-rings cannot be short-circuited and the brushes raised. Firms are already struggling with these difficulties and are seeking an alternative to the induction rotor excited with direct current. For example, the salient-pole rotor has been modified by placing an air-gap in the main poles in such a manner that, at starting, the cross flux becomes roughly equal to the main flux and thereby enables a very good starting torque to be obtained, and at the same time the rotor circuit, or a part of it, is laminated in order to enable the pulsating flux to traverse the whole circuit. It is necessary in all these cases to take care of the large pressure which might be induced in the exciting winding. Another of the various alternatives is the use of the salient-pole machine with a very wide pole-arc. Instead of using a damping winding with a high resistance (which would be very bad for synchronizing purposes) the low-resistance damping wind-

ing is used, the terminals of which are brought out to slip-rings connected to a resistance during starting. This resistance is short-circuited for synchronizing purposes, and other slip-rings are used for the exciting winding. With regard to the pull-out torque, it would seem that the induction-motor rotor would be better than the salient-pole rotor; but I should like to ask the author if he has studied what happens when the rotor is pulled out of synchronism to rather a low speed and allowed to run up again with the exciter connected to the slip-rings? A disadvantage with regard to the salient-pole type is that, as in the case of the rotary converter, the machine will not only run up but will synchronize itself, and is just as likely to pull in wrongly as correctly.

Mr. H. M. Sayers: Supply engineers, users of electrical energy and those who are their technical advisers, are all interested in the solution of the problem of low power factor, which is becoming important because three-phase supply will undoubtedly be the general system of transmission and distribution in this country. Direct-current supply has been in use for a long time and there are still some big systems with direct-current distribution, but some of those systems have losses of the order of 30 per cent between the units generated and the units sold. This fact indicates that they will not extend or perhaps survive. The low power factor of the simple induction motor discounts to a large extent the intrinsic advantages of three-phase distribution. There is waste of capital in nearly every part of the plant and the working costs are also increased, both from additional losses and from the amount of regulation required. That trouble is not nullified by any tariff arrangement whereby the supply authority is paid by the user for these extra costs. Therefore, any additional method of improving the power factor is to be welcomed. The motors described in the paper appear to improve the power factor very materially, and they offer the great advantage of being automatic in action. That they can maintain a leading reactive current up to and well beyond the rated full load is very important. As against these advantages there is the increase of 33 per cent in cost. The purchaser of motors for industrial uses will want to be convinced very fully that he will get adequate compensation for that increased cost. It appears to rest with the supply authorities to devise tariffs which will oblige the user to consider the power factor of his load. Other disadvantages are the existence of a commutator in this type of machine, and that they are hardly commercial in sizes below about 100 h.p., but the latter difficulty may perhaps be met, in the case of works employing a number of small motors, by providing an exciting circuit fed by one machine. The author appears to favour the three-phase winding of the rotor, and switchgear which leaves the winding in three-phase form in the machine working as a synchronous motor. This means that one limb of the three-phase winding is carrying the whole exciting current, which is split between the other two limbs, and that either the rotor copper or exciting energy could be economized. It might be worth while, at any rate in large machines, to alter the switchgear so that when running synchronously the rotor has a single-winding circuit. The title of the paper is a contradiction in terms, but this is owing to our not having a proper classification of nomenclature of motors. I would ask the author to give some further explanation of Figs. 9 and 10, in the latter of which apparently three dimensions are represented in a way difficult to follow.

Mr. W. E. Burnand: The advantage of the induction-type synchronous motor in being synchronized is that it enables a somewhat cheaper and more efficient type of exciter to be used than does the non-synchronous machine with phase advancer. Its field is limited by the fact that it is synchronous, as, if it is pulled out of synchronism, flickering of the lights results. Compared with the ordinary synchronous machine, the motor itself, together with the exciter, is much more expensive; the efficiency is lower and the pull-out torque is also lower. On the other hand, the induction-type synchronous motor will start up on full load. The self-synchronizing machine suffers also from the somewhat severe racking strains, approximating to twice or more full-load torque as the machine is pulling into synchronism, and slips a pole, or overshoots just as it gets into step. This being an alternating stress, first pulling forwards and then backwards, even though present for a very short period, has a far greater tendency to develop any possible slight slackness in the windings or elsewhere, than is the case with the asynchronous machine, where the pull is always in the same direction. Compared with the non-synchronous machine with phase advancer, it has a slightly cheaper exciter, because the phase advancer for the non-synchronous machine has a revolving field in which the rotor revolves, so that the field has to be laminated and the commutating conditions are more difficult. That, of course, again adds to the cost. Again, the phase advancer in the case of the non-synchronous machine has practically series characteristics. That is shown clearly in curve C of Fig. 1, from which it will be seen that the power factor is good on the higher loads but gets bad on the light loads. At the same time I think that curve C under-estimates the advantage of the phase advancer on a non-synchronous machine. An improvement can be obtained by working the phase advancer with a magnetic circuit nearer the saturation point, in which case a compound-winding effect is obtained through a fairly wide range. I do not think that this is the limit for the phase-advancer arrangement. I believe it is possible for a shunt characteristic to be superimposed on the top of the series, which condition is essential for perfect power-factor compensation from no load to full load, though I recognize that this is a difficult problem as light load is approached. From the figures given in the paper the increase in cost is from 20 to 30 per cent. The only machine having this arrangement that I have met with is a 300-h.p. motor on a 3 000-volt three-phase circuit. The current on light load was 40 amperes, which shows that the magnetic density was too high, and the addition of an exciter reduced this to 9 or 10 amperes at a total cost, I am given to understand,

of £500 to £600, which is rather a big price to pay for this reduction in current. There is another advantage possessed by the "inverted" machine, mentioned on page 172, i.e. a somewhat higher efficiency can be obtained, because the cross-sectional area of the magnetic circuit is approximately the same both in the secondary and in the primary, and by making the primary the inside a smaller proportion of the magnetic circuit is obtained subject to the alternating flux. This results in a decidedly diminished hysteresis and eddy-current loss.

Mr. W. E. M. Ayres: I think that there is a great future before this type of motor because it has the advantage of high power factor combined with high starting torque, and does not require skilled synchronizing. There are one or two points in the paper

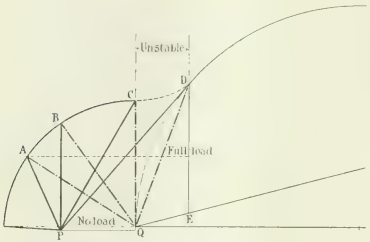


FIG. A.—Current vector diagram for induction-type synchronous motor.

to which I should like to refer. The first is in connection with Fig. 1 which, unfortunately, is drawn in such a manner as to be misleading and does not show the principal characteristics of the motor or the effect of its electrical proportions upon the performance. Fig. A shows a corrected current vector diagram as it would appear for an average motor designed to work at 0·9 leading power factor at full load. The full-line vectors from the origin P are stator currents, and the broken-line vectors from the origin Q represent the rotor currents. It will be noticed that at about 40 per cent overload the power factor is unity and that at higher loads the power factor begins to lag until at the point C the whole of the exciting current supplied to the rotor is required to produce torque, and the magnetizing current is drawn from the line. The agreement between this figure and Fig. 14 in the paper is obvious. At loads greater than that represented by PC the motor breaks down as a synchronous machine and operates as an induction motor, and the current increases to a value represented by PD where DE is equal to, or greater than, CQ. The region between C and D is unstable, but it must not be thought that the current is of a steady value at D, as the slip is fluctuating owing to the superimposed alternating and exciter voltages. The current will fluctuate from about 0·5 to 1·5 times the value PD. I wish to point this out, as some manufacturers are offering machines with lower starting currents at the expense of overload capacity and stability. The starting current of a well-proportioned induction-type synchronous motor designed to work at unity power factor is about 1·7 times full-load current for full-load torque. This, however, is equivalent to only 1·36 times for an induction motor of 0·8 power factor, which is by no means excessive. The author has not been quite fair to the phase advancer. Fig. 1 (curve C) represents a phase advancer connected to a motor having a magnetizing current as large as is required for a synchronous motor, whereas it should normally be about one-third of this value. Moreover, the current locus is not a circle struck from one centre but a curve as shown in Fig. B. From this figure it is seen that the power factor is above 0·98 for any value above one-third full load. Fig. 13 shows the limiting slip for synchronizing against various load torques. The author calculates that from 1·06 per

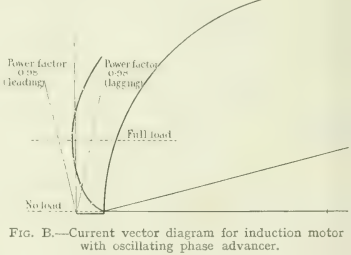


FIG. B.—Current vector diagram for induction motor with oscillating phase advancer.

cent slip, which is quite normal for this type of machine, the motor will synchronize against 96 per cent of its maximum synchronizing torque. Now I suggest that these are not the normal conditions to be met in practice. A motor may have to start up against very heavy loads, but it is never required to synchronize against such load torque. The limiting feature is the amount of synchronizing torque required to accelerate the moving masses through slip values in half a slip cycle. Fig. C shows how the limiting features may be plotted for a standard line of motors having similar characteristics. Inertia/kVA is plotted against speed in revs. per minute for a slip value of 1·25 per cent and normal load torque T_l. Curve I shows the limiting inertia for synchronizing, and curve II is plotted from the rotor weights and dimensions. The difference between these two curves is the amount of inertia which may be included in the connected machine. Curve I is plotted from the formula

$$\omega \sqrt{\left[K_1 \times \frac{\gamma \times \text{(kilovolt-amperes)}}{\text{kilogram-metres} \times \text{metres}}\right]}$$

Curve III shows the condition of perfect resonance which would cause dangerous hunting. This curve is plotted from the formula

$$\text{Speed (r.p.m.)} = \sqrt[4]{\left[K_2 \times f \times \frac{\gamma \times \text{(kilovolt-amperes)}}{\text{kilogram-metres} \times \text{metres}}\right]}$$

where ω = slip value in mechanical radians per second,
f = periodicity of supply,
γ = overload capacity in terms of full load,
K_1 and K_2 are constants.

These curves show at a glance the whole information required by customer and designer.

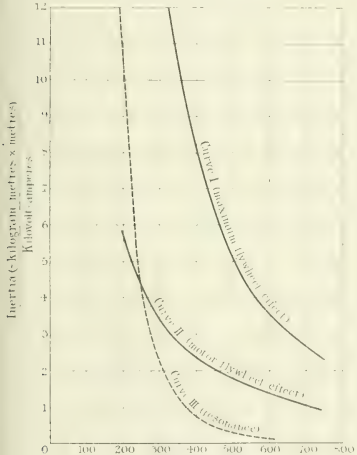


FIG. C.

The author's assertion that open-circuit rotor voltage and exciter voltage are beyond the designer's control is only partly correct, as a great variety of connections are used in the exciting circuit. Not all motors have three-phase rotors, and only in some cases is one phase loaded twice as heavily as the others. His formula should be qualified as applying only to the connections shown in Fig. 15. I think that the author has not been quite fair to his subject in the matter of comparative price and efficiency. The table in the next column is a typical comparison for a large size of motor, viz. a 1 200-h.p. compressor motor.

For obvious reasons the prices cannot be given here, but there was a maximum difference of 3 per cent between the highest and lowest tenders.

Type of Motor	Efficiency	Power Factor
	Per cent	
Induction motor ..	91·5	0·78
Induction motor with phase advancer ..	91·8	0·96
Synchronous induction motor	92	1·0

Mr. J. H. Johnson: Those who have been associated with the ordinary type of synchronous motor with salient poles will welcome such developments of the induction-synchronous machine as described by the author, and they can well realize its great future possibilities. The induction synchronous type of motor can be used for practically every class of industrial work, particularly for continuous output, but not for intermittent working. It is recognized that the machine must be capable of attention by unskilled labour if it is to compete and compare favourably with the ordinary induction type, and that simplicity and reliability are essential features. The author mentions that three-phase rotor windings are used in nearly all the motors of this type and that it is necessary to alter the connections of the winding when running with the exciter in circuit. This makes the motors rather complicated as compared with another type of machine that is on the market in which the exciter is always in circuit, the only switchgear required being a 3-pole or 4-pole switch for the stator and an ordinary 2-pole liquid starter for the rotor. The simple form of control gear in this type of machine is identical with that of the ordinary induction type of motor. The starting torque obtainable is at least two to three times the full-load torque, and the motor synchronizes readily with full-load torque. It has been questioned whether the advantage of this type of motor was due to the high starting torque or to the high power factor. I think it is probably due to both and also to its capability of doing useful work as well as improving the power factor of the whole system. This will appeal to supply engineers as well as to actual users, including those who have their own private supply. Recently a 150-h.p. induction-synchronous motor-generator was installed to supply a fairly constant load, where the alternating-current mains were already loaded. If an induction motor had been installed another feeder would have been necessary, the power factor of the system being about 0·6. By putting in a machine of the new type with a power factor of 0·8 leading, the power factor of the system was raised from 0·6 to 0·8 and a new cable costing about £500 was saved. With regard to the minimum size of induction-synchronous motor that can be employed, some of these motors are as small as 50 b.h.p., 750 r.p.m., running at the end of a long feeder with very satisfactory results. A high starting torque presents no difficulty at all with the motor having a two-phase rotor winding. This winding is patented, and is only made at present by one firm. This motor is capable of developing three times full-load torque, or even more, and with an air-gap about

50 per cent greater than that of an ordinary induction motor. It is advisable to keep the exciter voltage as low as possible so that the induced voltage in the rotor circuit shall be a minimum. Motors which have three-phase rotor windings and use only one or two phases when running synchronously, are certainly at a disadvantage as compared with the type of machine previously mentioned where two-phase windings are used on the rotor, the current in this case being equally divided between them, thereby resulting in equal heating throughout the machine. The cost of the induction-synchronous motor has been stated in the discussion to be as high as 33 per cent above that of the induction motor. I think this figure is much too high. On the other hand, another speaker has estimated the extra cost of the induction-synchronous type of machine as only 3 or 5 per cent, which I consider to be too low. In any case the extra cost, if any, should be very small for a given size of core, except for the extra cost of the exciter where separate excitation is not available. I should like the author to say what he considers the maximum induced voltage should be on this type of machine at the moment of starting. At the present time it is possible, by means of a suitable earthing device, to protect the operator at the moment of starting or during the first revolutions of acceleration, after which the voltage induced in the rotor falls to a very low figure.

Mr. J. K. Catterson-Smith: I should like to know whether the author has applied direct-current excitation to cascade motors. It is well known that the power factor of cascade combinations is very low, and its improvement is a matter of importance owing to other special features of cascade motors. I consider the oscillograms in the paper to be very helpful as a record of the action of the motor during the period of synchronizing, and it occurred to me that further information might be obtained by separating the d.c. and a.c. components of the rotor current which are shown, for instance, in Fig. 8. In order to obtain this, two motors, a 6-pole synchronous motor with salient poles and the usual d.c. rotor, and a 6-pole induction motor, are mechanically coupled, and a Duddell oscillograph arranged to record the three-phase line current to either motor and also the d.c. and a.c. rotor currents. It is then possible to study the conditions during synchronizing, the double-frequency currents in the d.c. circuit, and the conditions under which the set will run at sub-synchronous speeds, etc. The motors available are only of 5 h.p. rating and therefore, as pointed out by the author, of little commercial value, but I find the records obtained of interest and hope to be able to publish them at an early date.

Mr. W. M. Selvey: The firm with which the author is connected have recently converted for me a large motor of the induction type into the synchronous induction type, and it has been running now for 3 or 4 weeks. I have experienced none of those troubles which I was told might occur. If a large induction motor is underloaded for long periods and yet has to take peak loads up to its full-load capacity, it is possible to inject into the motor, by means of a separate exciter, a magnetizing current which will give the user of the motor complete control over the power factor. With a large motor the question of cost of alteration is not prohibitive and I think a new piece of apparatus is provided which will be of very great service to the electrical industry. There are certain classes of work for which it is peculiarly suitable. If this is brought home both to supply authorities and to users, I am certain that many large motors running to-day will be converted without any particular trouble other than the changing of the winding and the provision of the necessary switchboard.

Mr. H. Burge: I have recently used a scheme for the rotor connections which is somewhat different from that shown in Fig. 15. Instead of having a three-phase rotor in which the heating in one phase is 4 times as great as in the others, I have used an ordinary two-phase winding. The dippers of the liquid starters are earthed. This enables the exciter, the field and the shunt regulator, all to be at earth potential, and therefore perfectly safe to handle although there may be 2 000 volts on the rotor at starting. There is no other switchgear. It is true that there is a very high saturation in the middle of the pole with such a winding, but the two advantages of equal heating and of perfect safety I think outweigh that disadvantage. I have seen many of these machines in operation and I can corroborate what the author says about their synchronizing power. It is obvious that all the uncertainty of starting, synchronizing, and hunting met with in the old synchronous motor is entirely eliminated.

Mr. L. H. A. Carr (*in reply*): In reply to Dr. Smith, it is, I think, primarily the high starting torque of the induction-type synchronous motor which renders it so valuable, since power-factor correction without high starting torque can be obtained with the ordinary salient-pole synchronous motor. At the same time the smaller cost of a synchronous-induction motor installation is probably less than the cost of a salient-pole installation, owing to the relatively large cost of the auto-transformer needed for the latter. With regard to the air-gap, it is usual for the air-gap of synchronous induction motor to be some 33 per cent larger than that of the corresponding induction motor, but this question of air-gap is surely not serious if we bear in mind the thousands of induction motors that are running satisfactorily in this country. I must emphatically disagree with Dr. Smith's inference that low-voltage commutators cannot be satisfactorily designed. The modern low-voltage d.c. commutator is absolutely reliable and sparkless. Dr. Smith refers to a special type of salient-pole machine with large pole arcs and separate auxiliary winding for starting. So far as I am aware only one machine of this type has been built—in Germany—and the results obtained with it are inferior to those obtained with the machine described in the paper, in addition to the more expensive construction involved by providing two distinct secondary windings, one for starting and the other for running. With regard to the question of connecting the exciter in circuit at low speeds, I experimented with this method of connection some 10 years ago

The exciter armature was permanently connected in the rotor circuit, and while the arrangement worked all right, the exciter building up and the machine synchronizing itself quite satisfactorily, the method was discarded since the fluctuation in the line current lasted a considerable time as the machine was approaching synchronism. This prolonged oscillation is unavoidable if the exciter is connected in circuit from the start, whereas by switching the exciter into the rotor circuit when the machine is up to full induction-motor speed, the disturbance lasts only some 4 or 5 periods, that is, about 0·1 second on 40- or 50-period machines.

Mr. Johnson also refers to the fact that synchronous induction motors will start up quite well if the exciter is connected permanently in circuit, though he omits any reference to the consequent disturbance on the line.

Owing to the fact that the rotor is cylindrical, a synchronous induction motor will not synchronize itself without field excitation, and cannot therefore synchronize itself with the wrong polarity as Dr. Smith suggests. It pulls itself into step after the excitation is applied, and can synchronize itself only with the correct polarity. If the excitation is switched on at the wrong moment, the machine merely slips a pole before synchronizing, which is the cause of the high current-kick previously mentioned. It should be pointed out, however, that the current-kick does not take place as the rotor is slipping through the generating pole, but after this, when it is motoring both as a synchronous machine and as an induction machine, the two motoring currents adding up to form a peak.

In reply to Mr. Sayers, Fig. 9 is simply a curve showing the velocity of the machine as a function of the time. In Fig. 10 the base line represents the displacement of the motor, with reference to the no-load position as a synchronous motor. Curve A shows the synchronous torque. The snail-like curve B is the induction-motor torque. This curve shows that if excitation is switched on when the displacement of the rotor, measured in a lagging direction, is 90° the lag of the rotor increases, up to a maximum of about 105° after about 0·12 second. At this moment the speed is synchronous and there is no induction-motor torque. Still tracing out the snail curve, the rotor is seen to move forward relatively to the synchronous field, i.e. to the left-hand side of the figure, reaching its maximum speed just after 0·4 second. The ordinate of the B curve at this point is proportional to the (negative) torque exerted as an induction motor, and hence also the slip, thus serving as a measure of the speed. Continuing in this manner, the overshooting of the rotor and its final settling down to a displacement of 30° are clearly shown.

I cannot agree with Mr. Burnand that during the period of synchronization dangerous stresses are set up in the stator windings due to excessive currents. Certainly the current may momentarily reach twice its normal value, but all induction motors are built to withstand such currents, and the mechanical shocks are far less than are experienced, for example, by a winder or haulage motor. Though my experience of this class of machine extends back over the past 13 or 14 years, I have never heard of any case of trouble due to this cause.

I do not agree with Mr. Ayres that Fig. 1 is misleading. It shows in one diagram the type of performance to be expected from each of the three kinds of machine described. At the same time one is glad to have the fuller Figs. A and B put forward by Mr. Ayres. Fig. B relates, of course, to a machine with a larger, and hence more expensive, phase advancer than is allowed for in Fig. 1, with correspondingly greater power-factor correction, particularly in the region of one-half and one-third full load; and, further, Fig. B takes account of saturation in the phase advancer, which Fig. 1 (taken from Fig. 4 in Dr. Kapp's paper* on "Phase-advancing") does not allow for. While the magnetizing current of a salient-pole synchronous motor excited from the alternating-current mains may be 3 times as big as the magnetizing current of the corresponding induction motor, this proportion is not correct for a synchronous induction motor, particularly for one designed to run at from 0·8 to 0·9 leading power factor at full load.

Mr. Ayres criticizes my statement that a synchronous induction motor will synchronize against a torque of 96 per cent of its (synchronous) pull-out torque, with the remark that such conditions are not usually met with in practice. This is true, but my statement remains, nevertheless, a fact, and this fact is a useful guarantee that there will be ample margin for synchronizing against any loads that may be met with in practical operation. At the same time, should a motor fall out of step due to an abnormal and excessive drop in the supply pressure, such as might occur with a short-circuit, this property may come into play most usefully when the pressure commences to rise as the system recovers itself. As a matter of experiment, almost any synchronous induction motor coupled to a direct-current generator for testing purposes (which forms a combination having relatively low inertia) will exhibit the phenomenon of pulling into step against 96 or 98 per cent of its pull-out torque. A critical excitation for the synchronous induction motor can be found where, by diminishing it ever so slightly, the machine falls out of step into the "fluctuating" induction-motor condition, and by increasing it again to the original value the machine pulls back into synchronism. I have carried out this test on a number of machines not only with three-phase but with single- and two-phase rotors.

Mr. Ayres's Fig. C is most interesting, but I doubt its accuracy. It would appear from this curve that a synchronous induction motor will synchronize itself only when the total stored energy or flywheel effect in the system does not exceed some $2\frac{1}{2}$ to 3 times the stored energy of the motor alone. This is absurd; the factor should be at least some 15 or 20 for 50-period machines, and more still for machines of a lower periodicity. Mr. Ayres suggests that the employment of various connections in the rotor for starting and excitation is within the designer's control, and to this

* *Journal I.E.E.*, 1913, vol. 51, p. 243.

extent the relation between excitation voltage and open-circuit voltage at start may be varied. This is true, but only to a very limited extent, and then mainly owing to the less efficient use of the rotor copper. This will more easily be understood if the same rotor, with uniformly distributed winding, be in imagination connected up in different ways. If connected three-phase, star or mesh, or if star-connected with one leg carrying no exciting current, which is also equivalent to a single-phase winding covering two-thirds of the periphery, then the production of a given sine wave of flux round the periphery will require a certain number of watts in the exciting circuit, the same in each of the above cases. With any other method of connection not equivalent to the above, the necessary watts consumed for the same fundamental sine wave of flux will be increased. In particular, if the whole rotor winding carries the same current the loss in the rotor will be increased by 12 per cent to give the same fundamental flux wave. In this case the ratio of exciting voltage to open-circuit voltage will obviously be increased by 12 per cent for this reason alone, but as this is equivalent to the use of a permanent resistance in series with a three-phase rotor for no other purpose than to increase the exciting voltage, the inefficiency of this method of excitation is at once apparent.

Mr. Johnson's claims in favour of the two-phase rotor are therefore not borne out when the whole of the facts are examined. The question of equal heating around the rotor is, as has been pointed out in the paper, practically immaterial. The heat conductivity of the rotor is such that the temperature-rise is very nearly uniform, just as is the case with a rotar converter armature which is similarly unequally loade

Both Mr. Ayres and Mr. Johnson claim that I hav over-estimated the difference in price between the sy chronous induction motor and the plain inductio motor. I believe they are right. I have, howeve been very anxious not to give any figures which cou not be borne out in practice, even in the most extren cases.

In reply to Mr. Johnson, a voltage of 2 000 induc in the rotor at starting presents no difficulty, and believe that several firms work up to this figure as maximum.

Mr. Catterson-Smith raises the question of casca motors. While I have never actually applied direc current excitation to a combination of two motors cascade, it is a perfectly feasible proposition and cou be employed if desired. Several "cascade" motc made under Mr. Hunt's patents have been arrang for d.c. excitation as synchronous induction moto though I believe that they have been arranged to r synchronously at only one speed. I shall look forwa with interest to the publication of Mr. Catterson-Smit experimental results.

With reference to Mr. Burge's remarks, I have alrea referred to the disadvantages of a rotor where t whole winding carries the same current. I would al point out that with the 3-pole switch shown in Figs. 15 and 15 (*d*), as well as with the series-parallel arrang ment, the exciter and field regulator are complete isolated from the rotor circuit at the time when t high pressure is induced in the rotor at starting.

North-Western Centre, at Manchester, 29 November, 1921.

Mr. E. P. Hill: The synchronous induction motor has an advantage over the ordinary synchronous motor on account of the additional starting torque and the possibility of pulling into step by reason of the oscillation above mean induction motor speed due to the pulsating effect of the combined induction motor and synchronous torque. In the case of a direct-driven highly fluctuating load would it not pay to arrange the machine so that it would not carry the very heaviest peaks without pulling out of step, as the machine would instantly pull in again, and a cheaper machine would carry the load? With reference to the pulling into step, there is a possibility that the rotor will approach synchronism with an opposite polarity induced from the stator to that which would be obtained with separate excitation. The rotor would have to slip a pole before pulling in, thus resulting in a surge of current, so that under similar loads different pulling-in times would occur. The author mentions the possibility of the "inverted" type of machine. Would the starting performance be improved by constructing the field system with polar spaces, as there would be more room for this if required on this type? The reduced core losses of a synchronous induction motor (possibly due to difference in field form) warrant further investigation. I would suggest that the addition of a bibliography of references to earlier technical information would be of assistance to students of this subject. In conclusion I would a how long these machines have been manufactured this country.

Mr. A. B. Mallinson: There are three fields op for this type of motor: (1) Where there are big install tions which make their own power and have troub due to their cables being overloaded, owing to low pow factor. It will enable such stations to avoid spendi money on new cables. (2) Where big installatio which take power from a public supply have too lo a power factor and are forced by the supply authoriti to install such motors. (3) For any drive (possibly isolated motor) which by the nature of the load is su able for this class of motor. This, I think, is a very b subject and one that wants mature consideration b our power supply companies. A consumer cann be expected to install a machine which is 1 per ce lower in efficiency, costs anything from 25 to per cent more, and is not going to benefit hi personally; but it is very much to the interest the supply companies that these machines should in wherever the load is suitable, because it will bene them in their network of supply. I propose that t supply authority should go to the prospective custom and say: "We suggest that you install such a machir It will be 1 per cent lower in efficiency but we w reduce your bill 1 per cent. The motor will cost 40 p

cent more but we will pay the extra amount." It is really a sound way of looking at the problem, as it will enable the authorities to give supplies to more customers without spending the equivalent and more in new mains.

Mr. G. A. Juhlin: The question of power factor is a very serious one for authorities supplying a purely industrial load, and in some instances contracts covering the supply of power stipulate that the power factor of the load must not fall below a certain value. The difficulties with respect to power factor are increased in cases where the load is of a fluctuating nature. As an example a case may be cited where an induction motor was installed for driving a rolling mill. It was found to be impossible to keep the motor loaded up to its capacity owing to the difficulty of keeping all the rolls going. During the time of reheating the motor was running light, with the result that the power factor was very much below the figure stipulated in the contract. The supply authority claimed a higher rate for the power, which meant a serious loss to the consumer. The difficulty was solved by changing the induction motor into an induction synchronous type of motor, with the result that a leading power factor was obtained. It would seem logical to suggest that as a low power factor is penalized a rebate should be given when consumers take power at unity or leading power factor. The author has dealt fully with the question of the construction of the motor and there is no feature in which it differs materially from the standard type of induction motor. Objections have been made against the motor on the score of the air-gap not being as large as in the ordinary type of synchronous motor. I think this criticism is not justified, considering that millions of horse-power of motors of the ordinary induction type are in satisfactory operation, and that the air-gap on a standard induction motor is smaller than that of a synchronous induction motor of the same output and speed. I am glad to see that the author has emphasized the excellent damping obtained with the synchronous induction motor. Experience has shown that hunting is non-existent, so that no trouble need be anticipated on this account. The author has dealt thoroughly with the theory of the pulling into step of the motor, and the conclusions arrived at are borne out by actual operating experience, which has been satisfactory in every respect. The author has also dealt with the advantages of the synchronous induction motor over some other means of obtaining power-factor improvement. I think it would be useful if he would give some information as to the relative cost and size of static condensers.

Mr. G. F. Sills: It is very gratifying to find that designers in this country have given this matter their serious attention. In the past we have rather lagged behind some other countries. As long ago as 1910 it was quite a common practice in Canada to use synchronous motors, particularly for pumping plant. This type of motor was very often installed for quite small powers, whereas in this country 11 years ago it was very difficult to get engineers to see its advantages.

Mr. W. Stansfield: The firm with which I am connected has been manufacturing a self-synchronizing type of motor for the past 12 or 13 years, and we can claim to be pioneers in this field. During this time the firm has supplied a large number of such motors for a multitude of purposes, these having various degrees of power-factor-correction capacity relative to the power delivered by the machines, this proportion varying in amount from machines operating as pure rotary condensers to machines operating with full-load power factors as high as 0·9 and even unity. The kVA capacity of motor desirable for a given installation varies according to the extent of wattless load to be compensated for, and the power required by the driven machine. As mentioned by the author, it is not desirable to work at too high a power factor on the motor, on account of economically obtaining the required overload capacity. For some duties a leading power factor of 0·8 is as high as it is desirable to go, and for others 0·9 is quite suitable, this latter figure being suitable for duties such as air compressors, which do not demand any great excess of torque above normal full load. It must not, of course, be understood that a 0·9 power factor motor has of necessity a low overload capacity, but, as indicated in the paper, it is merely a question of obtaining the overload capacity economically in a given machine. In some cases where a large amount of leading wattless kilovolt-amperes has been required and only a relatively small amount of power has been demanded by the driven machinery, power factors as low as 0·3 leading have been installed. Generally speaking, however, where a low leading power factor is desired, unless a heavy starting torque is required, the cheaper motor, i.e. the salient-pole type machine, may be used. The somewhat heavier starting current required by the salient-pole machine, however, and the necessity for using an auto-transformer, sometimes prohibit its use. In such cases the type of machine at present under discussion is used. There are various methods of winding and connecting the rotor, according to the duty, etc., which the motor has to do. For duties where the starting torque is light compared with the kVA capacity of the motor considered as kilowatts, i.e. at unity power factor, and where damper windings are not required, the plain single-phase winding is applicable. Where the starting torque demand is high enough to make a single-phase winding inadvisable, and the duty does not require a damper, the rotor can be wound with two phases out of three, i.e. with no winding in the pole portion of the core, the motor being provided with three slip-rings and starting up as a two-phase rotor, thus neutralizing the single-phase effect at half speed and enabling the motor to start up against heavy starting torques. Where a damper winding is necessary a two-phase winding can be used, consisting of the main winding occupying two-thirds of the perimeter, and an auxiliary winding in the remaining one-third. This auxiliary winding can be wound to give either the same voltage as the main winding by using a smaller section of conductor, or the same section of conductor may be used and a lower voltage obtained on the auxiliary winding. This lower voltage is an advantage, as the rotor will not then have to withstand such a high voltage across the outers, as, generally speaking, this type of motor is provided

with three slip-rings, one ring being common to the two windings. Damping can be provided economically by various other methods of arranging and connecting the rotor winding, including that indicated in the paper. This damping effect is very desirable in some cases, and in others it is absolutely essential. I am putting on the table, for inspection, sundry photographs of machines which have been built by the Lancashire Dynamo & Motor Co.

Mr. V. Mallalieu: The importance of power-factor correction has been recognized for some time and there are many cases where industrial users have installed synchronous condensers merely for this purpose. If it pays them to do that it must pay them very much more to put down a machine which will correct the power factor and at the same time do useful work as a motor. Many people do not realize what low power factors are met with in practice. I have seen big installations where the power factor is as low as 0·5, which must be a very big handicap to the supply authority. In one of these cases the owners, in putting down a more recent installation, have installed a synchronous induction motor of 150 h.p., together with a number of small induction motors, with the result that the power factor of the new installation is 0·8. I also know a case of a small private plant in which the installation of a synchronous induction motor is now being considered. The generator is fully loaded in kilovolt-amperes, but the engine is not fully loaded. The owners want to put on an extra 60 kW, and this can be done by installing a synchronous motor, because 60 kW can be taken from the engine without adding any appreciable kilovolt-amperes to the generator. Many bad power factors are certainly partly due to inevitable causes, but a large number are caused by bad engineering. A non-technical man always wants a motor which is big enough, and he orders it without understanding the effect it will have on the power factor. Another prevalent cause is the use of low-speed motors; if we could persuade people to put in motors of higher speed and make more use of mechanical reduction gears, the power factor could be improved. On the other hand, a motor driving a very fluctuating load is bound to have a poor power factor. In such cases the power factor is always much less than that corresponding to the average load on the motor, since the power-factor curve is not straight. The average user will not pay for synchronous induction motors, or for any method of improving the power factor, unless he can see some return for it, and it rests with the supply authorities to make him do so. In Lancashire many supply authorities do not charge on the scientific basis of the maximum demand and a unit charge, and until they do that there is little chance of charging on kilovolt-amperes. It should not be difficult to charge on maximum kVA demand. I should like the author to give some more information about the starting currents of the synchronous induction motor, as it is obvious that the machine requires a big magnetizing current when running. He mentions an increase in the stator current when the motor is synchronizing and also if it comes out of step. It has been suggested that the motor need not necessarily be designed to cope with the biggest overload, because if it drops out of step it will go back when the overload is removed. I think that is wrong, because when the motor drops out of step the current is apparently doubled. I think also that the increase in the stator current when the machine is synchronizing is rather a disadvantage, as in the case of a big motor it means a large amount of current taken from the line. It is mentioned in the paper that there is some reason for converting the rotor into a primary, and the stator into the secondary in these machines. In all the examples which have been shown on the screen to-night, the stator has been the primary. I should like to have the author's opinion as to which method of construction we are likely to see in the future and whether there is any objection to making the rotor the primary.

Mr. W. Browning: I should like the author to give some information regarding the effect of the damping characteristic which some machines possess to a greater extent than others. Does it lengthen the time of coming into step, and what is its influence on the overload capacity? In practical work the time for correction of bad power factors is prior to the development of such a power factor, and it is at this stage that the supply authorities could help if they would. There is a large field for the application of the synchronous induction motor which the provision of a suitable change in tariff by supply authorities would help to open out. It is not always possible to prepare for power factor correction before the need arises, and to have to deal with an existing installation is rather a different matter. In many cases a synchronous induction motor is very difficult to apply, on account of the magnitude of its minimum size relative to average industrial motors. The solution then is either a synchronous condenser or a static condenser, and in many cases where the lengths of main cable are short the demands of the supply authority could probably be met by the use of a high-tension static condenser, this giving the relief to the supply mains and station.

Mr. R. Townend: The type of motor described in the paper has not been adopted in the past to an extent warranted by its characteristics and performance, but doubtless this will be corrected in the future as its advantages over the plain induction motor appear to be now more fully recognized. The principal obstacle in the way of its adoption is its higher cost, which the author gives as 25 to 40 per cent above that of a plain induction motor. In this comparison it would be interesting to know if the induction-type synchronous motor considered has the same general design of slots and windings as the plain induction motor. If this is so it would appear that a cheaper induction-type synchronous motor could be made by using a comparatively small number of large open stator slots, which arrangement would be undesirable in the case of the plain induction motor. Where only a low starting torque is required, the salient-pole synchronous motor has a few small advantages over the induction-type synchronous motor. The former machine will start as a squirrel-cage induction motor, will automatically pull into synchronism, is slightly cheaper than the latter, and for a given open-circuit rotor voltage

a higher direct-current exciting voltage can be used. Tests taken on a number of machines showed that the open-circuit rotor voltage was only about 20 to 30 per cent of the value obtained from the ratio of stator and rotor turns, this reduction being due to the screening action of the squirrel-cage damper and solid poles.

Mr. D. S. Paxton: I should like to know exactly what the author means by his statement on page 172 that "since the extra loss is only 1 per cent, the apparent efficiency of the leading component is of the order of 99 per cent." The extra loss of 1 per cent is, I take it, that referred to under the heading of "Efficiency," so that for every 100 units of real energy put into the synchronous induction motor, one less is given out mechanically at its shaft end than in the case of the ordinary induction motor. I cannot understand how this 1 per cent difference in what may be termed the useful component of output of the two types of motor can be added to, or subtracted from, or compared in any commensurate way with, the wattless or exciting component of current at 90 degrees to it, giving this an apparent efficiency of 99 per cent. In the same paragraph the author states that "the capital cost per leading kilovolt-ampere is one-third of the capital cost per kilowatt." It would perhaps be more correct to say "the capital cost per exciting kilovolt-ampere." Electricity supply authorities might with advantage give some careful thought to the question of devising a tariff that would reward the high power-factor consumer and penalize in a fair manner the very low power-factor consumer, who is a nuisance not only to the supply authority but also to all neighbouring consumers in the many cases to-day where distributing mains are working at the top of or beyond their intended capacity. A reliable maximum kilovolt-ampere demand recorder seems to be lacking, and it can only cause irritation and annoyance if a kVA demand tariff is initiated, only to be worked on a basis of the estimated, instead of the actually recorded, maximum kVA demand, as has been known to occur in some cases. One of the chief advantages of the synchronous induction motor in comparison with an induction motor with phase advancer is, to my mind, the fact that the commutator deals with direct current and not with alternating current. My first experience of an alternating-current commutator was in about 1903 and after a short time I was extremely glad to get rid of it. Since then I have from time to time used alternating-current commutators in various guises and on each successive occasion have been increasingly glad to get rid of them. Direct-current commutator troubles are, of course, relatively insignificant, and, as far as possible, a commutator that will commutate in a neutral zone is to be preferred to one which endeavours violently to reverse a current at any convenient or inconvenient point on a sine curve. I should like to know whether an existing induction motor can, without much difficulty, be converted to one of the synchronous type by the addition of a direct-current exciter, and what are the limiting factors governing the possibility.

Mr. J. Frith: There is one disadvantage about the synchronous motor which has not been pointed out. The rolling mill has been spoken of as being a suitable case for its use as having a low average load and therefore an induction motor driving it would have a very low average power factor. A rolling mill is, however, almost always dependent upon a flywheel and cannot, therefore, use a synchronous, constant-speed motor; it must be driven by a motor having a large speed-drop.

Mr. R. G. Kilburne: On page 166 it is stated that with the corrected induction motor the power factor lags as the load decreases, but it is my experience that with the Kapp type of phase advancer the power factor does not lag, but, on the contrary, the angle of lead increases down to approximately half load, and in many cases the power factor is leading or unity down to at least $\frac{1}{4}$ full load. Fig. D shows the power-factor curve of a typical induction motor and phase-advancer set. It is interesting to note that the phase advancer when used in conjunction with an induction motor greatly increases the overload capacity. When designing the induction motor for use with a phase

Leading
Lagging
Power factor
A
B
A Typical power-factor curve of motor with Kapp phase-advancer
B Natural power factor curve of motor
Rating of motor = 320 b.h.p. = 365 r.p.m. = 200 volts
Rating in b.h.p.

FIG. D.

advancer it would be possible to cheapen the design by using deeper slots, etc., making it, in effect, a poorer machine and correcting its performance with a phase advancer. It would seem to be a serious disadvantage in the synchronous induction motor to make use of a large number of rectangular conductors per slot in the rotor. On page 172 the author refers to inverted machines. Some difficulty would be likely to arise in the case of high-tension inverted machines, and I should be glad to hear the author's views on this type. I should also be interested to know whether the author is familiar with the Hunt "cascade" type of synchronous motor. In cases where a large starting torque is required it is possible to run a machine of this type not only up to synchronous speed, but, if necessary, slightly above, and by this means it is possible to reduce to a very low value the current kick when synchronizing. In cases where a lighter starting torque is required up to, say, full load it is possible to make use of a short-circuited rotor without slip-rings, the direct current being applied to the stator. This overcomes the difficulties with the ordinary type of synchronous induction motor referred to above.

Mr. T. Baxendale: Power station engineers generally will be pleased to hear that manufacturers are taking up the question of the low power factor of motors which,

besides the extra copper required in the cables, often means additional transformers and at times an extra generator on the bars purely to take up the wattless current. The capital laid out on these three items must be taken into consideration when charges are being fixed. I would ask the author to consider whether existing induction motors, some of a totally enclosed type, could be converted to the synchronous type, and also if it could be adapted to small motors of, say, 40 to 50 h.p., as in some cases there is quite a number of these, but no motors of 80 h.p. or more.

Mr. E. M. Johnson: It may be of some interest to mention a recent application of the synchronous induction motor in the case of a woollen mill which originally derived its power from a small steam set, and a direct-current generator. Subsequently additional power in the form of three-phase current was taken from the local supply authority, and it was decided to discard the steam engine and replace it by a synchronous induction motor driving the direct-current generator, thus improving the otherwise low power factor whilst retaining the small direct-current supply necessary for certain operations.

Mr. C. Rettie (*communicated*): The paper apparently deals with land practice only. What would be required for the electric propulsion of ships is entirely different from that which would be required on land, but certain problems apply to both. For instance, in the first battleship which was built by the Americans to be propelled by electricity, a type of motor was used which had a double winding on the Boucherot system. The motors used are induction motors; the first winding has a high resistance and a low induction; the second winding has a low resistance and a high induction; and there are no external resistors or collecting rings. The system was successful, but the low power factor necessitated the use of rather larger electrical machinery on the "New Mexico," the first battleship fitted, than is being supplied to other ships. In fact, in the case of the motors which are being built for the battleships and battle cruisers, the motors are wound with a low-resistance winding near the periphery of the rotor and beneath this is a high-resistance squirrel-cage winding. The low-resistance winding is connected to the slip-rings. There are no external resistors. In an article in the *General Electric Review* for February, 1921, by Mr. E. S. Hennings, it is admitted that the synchronous motor cannot be designed to give quite as much starting and pull-in torque as an induction motor, as it is not possible to obtain sufficient reversing torque without over-exciting the generator field. However, the tests made on the s.s. "Cuba," which is the first vessel to be driven by a synchronous motor, showed that such high values of reversing torque are not necessary and that the propeller could be reversed on the induction-motor torque characteristic in 13 seconds.

Mr. L. H. A. Carr (*in reply*): The question of pulling into step has been raised by several speakers. Fig. 13 gives curves for an average machine with stored energy corresponding to that of a compressor and flywheel. These curves show that while the machine runs at full load as an induction motor with a slip of just under 1 per cent, it will synchronize at that load with any slip up to a maximum value of $3\frac{1}{4}$ per cent, or, alternatively, since the limiting slip varies inversely as the square root of the moment of inertia, the stored energy in the system could be increased some 10 times, and still the machine would synchronize. This shows the large margin of power available for synchronization.

The question of tariffs is, of course, a matter for supply engineers, and not for the author, but since a unit of power at low power factor costs more to generate and supply than a unit at high power factor it seems certain that sliding scales of charges, based in some way on power factor, will become practically universal in the near future.

The rotary condenser has been mentioned. This is an uneconomical machine, as the following argument will show. If 1 unit of power, and 1 unit of reactive power be needed, then, with separate machines, the total capacity of the machinery installed must be 2 units, whereas if both duties are combined in a single machine, the capacity of this machine will be only 1·414 units, with consequent reduction both in first cost and in losses when running. It therefore follows that power-factor correction, where needed, should always be carried out if possible in a machine which is also doing useful work, by running it at a leading power factor.

Mr. Hill suggests that, in the case of a highly fluctuating load, a synchronous machine should be designed with a lower overload capacity, and allowed to fall out of step at the peak load. Generally speaking this is undesirable, since every time a pole is slipped the machine momentarily takes at least twice full load current, and if it slips many poles the effect on the line will be bad. In exceptional cases, however, with peaks of very short duration, where it is reasonably certain that the machine will not slip more than one pole (corresponding to only 4 or 5 periods of supply) it is possible that it may be wise to take advantage of this characteristic. Further, as an emergency condition, say once or twice a year, there is no reason why this characteristic of the machine should not be allowed to come into play to prevent a shut-down.

In regard to the general question of overloads, any normal machine should be designed to carry any overload that it will meet. This point has been raised in connection with phase advancers. With the load usually met with in practice, if a machine will carry 70 or 100 per cent overload it is quite sufficient; the machine will never meet with a load in excess of this. If some other type of machine will stand 100 times full torque, it is no better for the purpose, and the property is absolutely valueless, since under no known circumstances can it ever be required or made use of.

The most likely cause of falling out of step is a sudden drop in the supply voltage, and here the synchronous induction motor has an advantage over the induction motor, since the pull-out torque of an induction motor drops as the square of the voltage, while that of the synchronous induction motor falls off directly as the voltage. A synchronous induction motor with a pull-out torque of $1\frac{3}{4}$ times full load will therefore be approximately equivalent in this connection to an induction motor with a pull-out torque of 3 times full load.

The question of polarity has been raised by Mr. Hill and other speakers. It does not appear that this matters appreciably, as, under the most unfavourable conditions of switching, the current-kick does not continue for more than 4 or 5 periods, and so is practically imperceptible on an ordinary ammeter.

In reply to Mr. Hill, I am certain that the starting performance would be impaired rather than improved by the provision of inter-polar spaces. This construction has recently been tried in Germany (see *E.T.Z.*, 27 October, 1921, p. 1217) with a machine having a (pole-arc/pole-pitch) ratio of 0·95, together with other special features such as a separate starting winding, etc., and I am convinced that the performance of this machine is inferior in every way to that obtained with the more usual type of construction.

In regard to Mr. Hill's inquiry as to the history of the synchronous induction motor, this type of machine was invented by Danielson in Sweden in 1900. In 1902 the Allmanna Svenska Elektriska Aktiebolaget patented it in Norway, Sweden, Switzerland and the United States, and have manufactured it ever since. In this country the first experiments were undertaken by the Lancashire Dynamo and Motor Company in 1906, and a year or two later they put this type of machine on the market. The British Westinghouse Electric & Manufacturing Co. followed in 1911. Since the armistice many other British firms have taken up the manufacture of these machines, followed by some of the Continental manufacturers. In the United States the synchronous induction motor has not, up to the present, been commercially manufactured.

A short bibliography of the subject has been added to the paper (see page 174), but I wish to warn students of the subject that there is a serious error in Dr. Rosenberg's paper "Self-synchronizing Machines" in the section relating to limiting slip for synchronization, so that his results in this connection are valueless. The error seems to be that, in dealing with the phenomenon which I have represented in Fig. 2, Dr. Rosenberg has taken the base line, which is the angle of lag of the rotor, to be proportional throughout its range to the total angle swept out by the rotor in its forward movement, whereas this is not actually the case. This question is dealt with more fully in my reply to Mr. Jakeman in the discussion before the South Midland Centre.

I fully agree with Mr. Mallinson's remarks on the wide field open to these motors, and would emphasize that the advantages with respect to power factor which these machines have over induction motors become increasingly important at low speeds.

Mr. Sills refers to installations in Canada, where synchronous motors have been used for pumping work. It is interesting to note that synchronous induction motors built in this country have been supplied to Canada for use with pumps and compressors. In general, however, it is found in both this country and the United States that the modern compressor can be started up quite easily with the ordinary salient-pole synchronous motor with auto-transformer starter.

Mr. Mallalieu suggests that, since a large direct current is required for excitation purposes, the magnetizing current taken from the line as an induction motor is also large. This does not necessarily follow, as the magnitude of the current in amperes depends on the number of turns in series. Since the number of secondary turns is kept low for other reasons, as explained in the paper, the secondary current is high in value, but the magnetizing current drawn from the line is usually only some 30 per cent more than that of the corresponding induction motor, while the starting current under full load is increased only slightly above that of a normal induction motor of the same power.

Mr. Mallalieu objects to the machine taking twice full-load current when synchronizing, which occurs when the moment of switching is unfavourable. I have already pointed out that this current-kick can be practically ignored, since in practice it lasts only for some 4 or 5 periods at most.

With "inverted" machines it is necessary for mechanical reasons to make the rotor (in this case the primary) winding of the barrel or diamond type, and this type of construction lends itself particularly to low-tension machines of relatively large output. Several of these have already been made with, so far as can be seen, no compensating disadvantages, but high-tension machines—particularly small and medium-sized ones—will probably continue to be made of the standard type.

Mr. Browning raises the question of damping. Synchronous induction motors with three-phase star-wound secondaries are very highly damped, the example shown in Fig. 9 (which is taken from an actual case) showing that with medium displacements of the rotor (that is where displacement is sensibly proportional to the restoring force) the damping is such that the amplitude of the oscillation is reduced to one-sixteenth of its magnitude in a single period of oscillation. High damping does not increase the time of coming into step, rather the reverse, since the phenomenon of damping is really the phenomenon of induction-motor torque looked at from another point of view. It therefore follows that high damping means a high induction-motor torque for a given slip, i.e. a low slip for a given load. High damping has no effect on the magnitude of the pull-out torque of the machine when in synchronism, but it plays an important part when overload is suddenly applied. The application of an overload causes the rotor to set itself back relatively to the synchronously rotating field, and, without damping, the rotor will overshoot its final steady position and might, under extreme circumstances, pass the maximum torque position and fall out of step. Damping, however, by coming into play immediately the rotor starts to move back relatively to the synchronous field, will reduce this overshooting effect and, with the high damping effect described above, the overshooting will practically disappear. High damping is therefore almost a necessity where the machine is subject to highly fluctuating loads.

In reply to Mr. Townend, the figure of relative costs of machines was made from a number of comparisons between an induction motor and a synchronous induction motor designed as such. The figures given,

however, err on the high side rather than on the low side, and it is probable that in a large number of cases the difference in cost is not so great as is stated in the paper.

With reference to Mr. Townend's other remarks, since, with large synchronous induction motors, the secondary is usually wound in two circuits, the excitation voltage works out at about 50 or 60, so that the difference between this figure and the figure of 110 usually adopted for salient-pole machines is not serious.

In reply to Mr. Paxton, since kilovolt-amperes are sometimes referred to as "apparent power," by the term "apparent efficiency" is meant 1 — (kilowatts lost)/(apparent power in kilovolt-amperes), and this figure is useful as enabling a comparison to be made with the efficiency of a machine of the same kVA rating delivering useful power. Generally speaking, any ordinary induction motor can by the addition of an exciter be converted to a synchronous induction motor, but of reduced power. The difficulty is one due to the heating limits on the rotor; it is impossible to arrange for the pull-out torque of the machine as a synchronous induction motor to be much greater than the full-load torque of the machine as an induction motor, and consequently the rating has to be correspondingly reduced.

Mr. Frith is quite correct in saying that where a flywheel is needed to assist at peak loads a synchronous induction motor is useless; the machine is limited to constant-speed operation. Yet, strangely enough, the only case that has come under my notice where an induction motor has been converted to a synchronous induction motor by the addition of an exciter after the main motor had been installed for some time, is the case of a motor driving a rolling mill, already referred to by Mr. Juhlin.

In reply to Mr. Kilburne, the curves in Fig. 1 were based on Dr. Kapp's paper * on "Phase-Advancing"

* *Journal I.E.E.*, 1913, vol. 50, p. 243.

for power-factor correction to unity at full load. With a much larger phase advancer, it is clear that a correction to unity can be obtained at half load or even one-third load as in the case he quotes, but the cost of the phase advancer must be increased many times to do this, and the disadvantage still remains that at very light loads the power factor lags, until at no load the machine takes precisely the same lagging current as if it were uncorrected. As has already been pointed out, the increased overload capacity obtained with a phase advancer is practically valueless to the average user, since it is never required. It is questionable whether a motor specially designed for use with a phase advancer would be appreciably cheaper than a standard motor, since the size cannot be reduced on account of the heating limits of the machine. I quite agree with Mr. Kilburne that high-tension machines, particularly in the smaller sizes, are not likely to be made of the "inverted" type. Several cascade machines (Hunt's patent) have been built for direct current excitation as synchronous induction motors, but Mr. Kilburne is mistaken in supposing that the current-kick is reduced by synchronizing from a speed slightly above synchronous speed. In any case whether the machine is running above synchronous speed, below synchronous speed, or even at synchronous speed itself, if the excitation is switched on at an unfavourable moment the machine has to slip through a "generating" pole before coming into synchronism with the consequent kick in current.

In reply to Mr. Baxendale, there is no reason why synchronous induction motors should not be used for power-station auxiliaries even if totally enclosed, though, for the reasons previously stated, the conversion of existing machines is usually impracticable. At the same time, it should be pointed out that the correct place for power-factor correction apparatus is where the bad power factor is produced, and not at the generating station.

South Midland Centre, at Birmingham, 14 December, 1921.

Dr. M. L. Kahn: The paper is a comprehensive review of the features and the working of the type of motor in question. It shows the various good points of the motor and there can be no doubt that this type of machine should be installed wherever a leading power factor and large starting torque are required. Where a power factor approximating unity between half load and overload meets the requirements of the case, the alternative of the combination of an induction motor and a Kapp phase advancer may be considered. The author has taken this in consideration and given on page 166 the advantages of the induction-type synchronous motor. To come to a correct conclusion in each particular case, the following disadvantages must also be taken into consideration.

(*a*) *Current surge when synchronizing.*—When direct-current excitation is switched on to synchronize the induction-type synchronous motor, the machine takes 2 to 3 times full-load current starting against full load. A motor working with the critical slip has a maximum torque during synchronizing. (See Mr. Lakeman's remarks on page 187)

$$T_m = T_f \sqrt{T^2 - T_f^2}$$

Reducing the slip below the critical value makes little difference, as only the last of the three items of the equation is affected, and this has not much influence. If we neglect it altogether we get a maximum torque of $T_f + T_s$, or $T_f(1 + k)$, where k is the overload capacity of the motor. The watt current taken by the motor is proportional to the torque, and therefore to $(1 + k)$ times normal full-load current. For a motor with an overload of twice full load we get, if oscillations occur, a switching-in current of 3 times full-load current. If synchronism is reached without oscillating, the maximum possible current is the same. The current depends on the moment of switching-in and must in any case be larger than k times full-load current.

(*b*) *Overloads.*—The induction-type synchronous motor has a lower overload than the ordinary induction motor

Combining the latter with a Kapp advancer materially increases its overload, the explanation being that if the same machine is used for any one of the three cases, the conditions of working vary as follows: As a synchronous motor it works with constant excitation fixed to suit full-load conditions, and this limits its overload. As an induction motor it takes, with increasing load from the supply, more and more wattless current, which maintains the field, thus giving an increased overload. The advancer combination takes more and more excitation both from the line and from the advancer as the load increases.

(*c*) *Efficiency.*—The losses of a Kapp phase advancer are only about 20 to 30 per cent of the rotor losses of the induction motor. These and the increases in the rotor loss due to the magnetization current are counterbalanced by the decrease in losses in the stator winding due to the improved power factor. The efficiency of the combination is practically the same as that of the ordinary induction motor. While in an ordinary induction motor or in a motor with a phase advancer, the magnetizing current is only about one-third of full-load watt current, and the corresponding losses are very small, the field losses in the synchronous motor are considerable, as the overload of this type depends on the ratio of magnetizing current to full-load current. If the excitation is adjusted to give a power factor near unity at normal load, the overload capacity of the induction-type synchronous motor is approximately

$$k = \frac{\text{field ampere-turns}}{\text{armature ampere-turns}}$$

In an ordinary induction motor the ampere-turns in rotor and stator differ but little. If, therefore, an ordinary induction motor is used as a synchronous motor with a direct current in the rotor corresponding to the full-load rotor current, the field ampere-turns are equal to the armature ampere-turns and the overload capacity is $k = 1$, i.e. the motor cannot give any overload. For an overload capacity of $k = 1{\cdot}73$ times full load the rotor ampere-turns must be increased $1{\cdot}73$ times. It is therefore impossible to use an ordinary induction motor as a synchronous motor, as the rotor losses would be increased $(1{\cdot}73)^2$, or 3 times above normal, to obtain a stable machine. The large difference must be made up partly by increasing the copper weight in the rotor and the size of the machine, and partly by increasing the losses in the rotor, with a corresponding decrease in efficiency. The reduction of the losses in the stator winding when the motor works at unity power factor is more than counterbalanced by the losses in the exciter and field regulator.

(*d*) *Cost.*—The ordinary induction motor takes its magnetizing current in the stator, where the temperature-rise is due to both copper and iron losses. The induction motor working with an advancer is excited in the rotor circuit where hardly any iron losses occur. The size of the motor can therefore be decreased. The synchronous type, on the other hand, must be made larger than a corresponding induction motor to allow for the increase in excitation required, mentioned under (*c*). The exciter which has to supply this large excitation energy will cost as much as an advancer, and the switchgear for the advancer combination is also simpler, as the throw-over switch (Fig. 15) can be omitted. The advancer combination will therefore be cheaper.

(*e*) *Commutator.*—The remarks made by the author in reference to the commutators of the Kapp vibrator are not correct. The vibrator is a low-voltage direct-current machine, as the whole construction shows. It works as a direct-current motor when it runs up to speed, and as a direct-current generator when it slows down. The commutating conditions are identical with those of a direct-current low-voltage machine where the brushes are set in the neutral position. The current varies only gradually, and is very low when the armatures are up to speed.

(*f*) *Slip.*—The increase of slip by a Kapp advancer is very small and can be neglected.

From the above consideration it appears to me that each case must be considered separately, and that whenever a machine with a power factor of unity meets the requirements the Kapp phase advancer combination offers the better proposition.

Mr. R. G. Jakeman: I am of the opinion that the author has not been fair to the other classes of machinery which compare with the motor he describes. He sets out the advantages of the latter but does not mention its disadvantages, the chief of which are perhaps the necessity for a low-voltage exciter, and the smaller overload capacity compared with a salient-pole machine. In spite of its drawbacks, however, there is no doubt that the synchronous induction motor is an excellent machine and has its place on the market as well as the plain induction motor with phase advancer. On pages 166 and 171 the author states that the rotor circuit is momentarily interrupted in order to include the exciter in circuit. It is only necessary, however, to open one phase, leaving the others short-circuited, and thus the disturbance caused is reduced. The method of connection shown in Fig. 15 (*b*) on page 171 is objectionable, because the exciter and regulator are connected to the high rotor voltage at the moment of starting. For this reason it is advisable to incur the extra expense of a 3-pole switch. The formula given in the Appendix for the exciting current is very useful for estimating purposes in order to determine the capacity of the exciter, but it is not satisfying to the designer. I have found the following method of calculating the exciting current very useful in practice. If the rotor is excited with alternating current, the shape of the M.M.F. distribution varies between a pointed form and a flat-topped form, and it can easily be shown * that neither of these forms is very different from a sine wave. The pointed form occurs when the current in one phase is a maximum and in the other two phases half the maximum in the opposite direction. If direct current is supplied to one slip-ring and taken from the other two in parallel, the current in each of two phases is half that in the other phase. The M.M.F. distribution with direct current is therefore of the pointed form. Hence, if the value of the direct current is made equal to the maximum value of the alternating current, the same M.M.F. is produced with both. Now it is a simple matter to calculate the alternating mag-

* *Electrician*, 1914–15, vol. 74, p. 42.

netizing current, so that the necessary direct current is obtained at once. The same remarks apply to the mesh connection in Fig. 15 (*d*), except that the exciter current is half as much again as for the star connection. The flat-topped form occurs when the alternating current is equal to $\frac{1}{2}\sqrt{3}$ of the maximum in two of the phases and zero in the third. This condition is obtained with direct current in a star connection when the current is supplied to one slip-ring and taken out at another, the third being open. In this case, therefore, the value of the direct current is equal to $\frac{1}{2}\sqrt{3}$ of the maximum value of the alternating current. Since the reluctance of the rotor is the same all round the periphery, the armature reaction can be added vectorially without appreciable error, since all the waves concerned are practically sinusoidal. With regard to the critical slip, Prof. Cramp has already pointed out that if α is as defined, the synchronous torque $= T_m \sin(p\alpha)$. I think, however, from a consideration of the subsequent mathematics, that α is wrongly defined and should be 90° different from what is stated. Rosenberg, in a paper * before the Institution, developed the following expression for the critical slip (reduced to the same

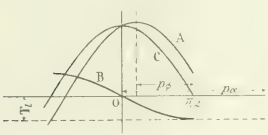


FIG. E.

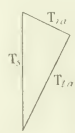


FIG. F.

form as the author's), $\omega = \sqrt{(T_m/pI)}$. For the case of the test-results given on page 170, $\phi = 1{\cdot}26/p$, so that the author's formula becomes $\omega = \sqrt{(1{\cdot}5T_m/pI)}$. This gives a value for ω about 20 per cent higher than Rosenberg's figure, and I should like to ask the author if he will explain the discrepancy. On page 167 the author states that the mean speed occurs when the *synchronous* torque is a maximum. As Rosenberg points out, this is not the case. The mean speed occurs when the *total* torque is a maximum. The result is that Fig. 11 is not quite correct, so that, as the final result is entirely based on Fig. 11, it can hardly be considered to be convincing. Finally, I think it would be more convenient if the critical slip in the final formula were expressed as a percentage instead of in mechanical radians per second.

(*Communicated*): On further consideration, the problem of the critical slip appears to lend itself to a comparatively simple solution. The induction torque may be considered as composed of two parts, a constant portion equal to the torque required by the load, which corresponds to the initial slip, and a portion oscillating about the line representing the load torque, proportional to the variation of slip. We therefore have the following oscillating torques combining to produce the oscillations in speed: t_{ia} = oscillating induction torque, and t_s = synchronous torque, where small letters represent instantaneous values. In Fig. E, curve C represents the total oscillating torque producing acceleration and deceleration of the masses. The variation in speed is at right angles to this (and not to the synchronous torque) and, since the oscillating portion of the induction torque is proportional to the variation of slip, it will be represented by curve B displaced 90° from curve C. The synchronous torque is the difference between curves C and B and is shown by curve A. It will be noted that the position of maximum total torque occurs behind the position of maximum synchronous torque. The resultant, T_{ta}, of T_{ia} and T_s (maximum values) can be seen from the vector diagram in Fig. F, where T_{ia} is at right angles to the resultant, and we have $T_{ta} = \sqrt{(T_s^2 - T_{ia}^2)}$. If we measure the angle $p\alpha$ along the base-line (where α is expressed in mechanical radians) and take zero angle where the total torque is a maximum, we have *

$$t_{ta} = T_{ta}\cos(p\alpha) = \sqrt{(T_s^2 - T_{ia}^2)}\cos(p\alpha)$$

Adding the constant portion of the induction torque, T_l, we have for the total torque acting,

$$t_t = T_l + \sqrt{(T_s^2 - T_{ia}^2)}\cos(p\alpha)$$

At the critical slip, when the motor only just reaches synchronism, the amplitude of T_{ia} must equal T_l, as will be seen from Fig. E, so that we have $t_t = T_l + \sqrt{(T_s^2 - T_l^2)}\cos(p\alpha)$. The retarding torques are as follows:

$I\frac{d^2\alpha}{dt^2}$ due to the inertia of the rotating masses, and

T_l due to the load.

Hence we have

$$T_l + \sqrt{(T_s^2 - T_l^2)}\cos(p\alpha) = T_l + I\frac{d^2\alpha}{dt^2}$$

or

$$I\frac{d^2\alpha}{dt^2} = \sqrt{(T_s^2 - T_l^2)}\cos(p\alpha)$$

The solution of this is as follows:

$$\tfrac{1}{2}\left(\frac{d\alpha}{dt}\right)^2 = \frac{\sqrt{(T_s^2 - T_l^2)}}{pI}\sin(p\alpha) + C$$

The constant, C, can be obtained by considering the point $\pi/2$ in Fig. E. Here $d\alpha/dt = 0$, since the point is at the crest of the wave B, and $\sin(p\alpha) = 1$, so that $C = \sqrt{(T_s^2 - T_l^2)}/pI$. Further, at zero angle the rotor is passing through the mean speed, so that $d\alpha/dt = \omega$, the initial slip in mechanical radians per second, and $\sin(p\alpha) = 0$. Hence $\frac{1}{2}\omega^2 = \sqrt{(T_s^2 - T_l^2)}/pI$, or $\omega = \sqrt{[2\sqrt{(T_s^2 - T_l^2)}/pI]}$. It will be seen that this is of the same form as Rosenberg's expression, but, as an approximation, he omitted T_l. My expression therefore gives a value 41 per cent higher than Rosenberg's. Taking the figures given in the author's test results and assuming that his calculation of T_s and I

* "Self-synchronizing Machines," *Journal I.E.E.*, 1913, vol. 51, p. 62.

* The term T_s is the same as the author's T_m, but α is not measured from the same position.

is correct, my equation gives the following values for the critical slip:

Calculated	Tested
3·46	3·04
3·13	3·05
3·09	3·05
2·74	2·70

These, with the exception of the first, agree very closely. The discrepancy may be due to saturation causing the overload capacity to be less than the value calculated by the author. My equation may also be written $\omega = \sqrt{2T_s}\sin(p\phi/\mu l)$, where ϕ has the same meaning as in the paper, and it would appear that in the author's expression the angle ϕ has too much significance. Comparing the three methods for various values of T_d/T_s, and denoting Rosenberg's value by unity in each case (since his result omits the value of T_d), we have the following figures for the critical slip:

T_d/T_s	Rosenberg	Carr	Jakman
0·1	1·0	1·33	1·41
0·2	1·0	1·28	1·40
0·3	1·0	1·23	1·38
0·4	1·0	1·18	1·35
0·5	1·0	1·12	1·32
0·6	1·0	1·05	1·26
0·7	1·0	0·98	1·19

Finally, converting the expression into more practical units, we have, since $\omega = 2\pi sf/100p$, where s is the percentage slip and f the frequency,

$$s = 100k\sqrt{(\text{h.p.}_m/fK)}$$

where h.p._m = overload capacity in horse-power as a synchronous machine, $K = We^2/2g$ = kinetic energy of the rotating masses in foot-pounds at the synchronous speed, and k = a factor depending on the ratio of the load to the overload capacity, which can be obtained from the following table:

load/h.p.	0·1	0·2	0·3	0·4	0·5	0·6	0·7
k	9·93	9·26	9·13	8·93	8·73	8·53	7·87

It will be noted that the case when load/h.p._m = 0·5 is the practical case of a machine with an overload capacity of twice full load, synchronizing when on full load. The only assumptions that have been made above are that it is permissible to use sine waves throughout, and that the influence of the exciter reactance on the induction torque is negligible. The error introduced by these assumptions is very small. In the case of a synchronous induction motor driving a reciprocating compressor, a margin should be allowed on the calculated figures, because the load is not constant during a revolution.

Major A. M. Taylor: The machine described in the paper will no doubt have a field where new machines are being introduced in which high power factor is of importance. I am principally interested in the question of adaptation of existing motors, and I would refer members to some results * given by Messrs. R. G. Warner and A. E. Knowlton. These results were so hopeful that Mr. Chattock agreed to carry out certain tests at one of our substations on a 160-h.p. induction motor driving a direct-current generator. The results obtained from this test were by no means as hopeful as the American tests suggested, and it was thought that perhaps the fact that the rotor was delta-connected was responsible for the inefficiency. However, the desirability of being able to convert ordinary induction motors with practically no alteration whatever into synchronous motors was so obvious that further experiments were carried out, this time on a 470-b.h.p. induction motor. These results were much more promising, and their weak feature was that the pull-out torque occurred at the full rated load of the machine. However, I anticipate that it would be possible to extend this point by some 17 per cent without overheating the rotor. The results of these tests are given in the appended table, and also the results which, I gather, from the very scanty data given in the paper, would be obtained at full load on a 160-h.p. Metropolitan-Vickers synchronous induction motor. For comparison the figures which I have obtained from Dr. Kapp, for a vibrator applied to a 160-h.p. motor, are also given. Referring to the results obtained with the 470-h.p. motor, it will be noticed that at $\frac{3}{4}$ load the overall efficiency including excitation is the same, both when the machine is working as a pure induction motor and when it is working as a synchronous motor. As we approach full load there is a positive gain in efficiency up to $2\frac{1}{2}$ per cent. This question of efficiency I believe to be of the greatest importance because it is obvious that if a consumer is offered a rebate for improving his power factor, and if in effecting this result he at the same time has to pay for a loss which previously did not occur, that loss may considerably or entirely offset the advantages he obtains in the way of rebate on account of the improved power factor. In col. 5 of the table will be found the interest and sinking fund charges on the extra cost of the phase-advancer equipment in the various cases considered, together with the annual charges on account of lost energy. The only data given in the author's paper which are available are those for full load in which he states that the loss is about 1 per cent. In order to compare the machine with the other machines I have assumed that the efficiency at $\frac{3}{4}$ load will be 2 per cent less than at full load. This figure is based upon the tests of the 160-h.p. machine at Birmingham, and if it is incorrect I should be glad if the author would give the correct figure (for 25 periods). On comparing this machine with a Kapp vibrator where the power factor can be maintained at practically unity from full load down to $\frac{1}{2}$ load, and where in consequence the overall losses are extremely low, it will be seen at once what an important factor the lost-energy charge is in the annual bill. At $\frac{3}{4}$ load, for instance, the comparison is as between, say, 0·39 (Metropolitan-Vickers) and 0·05 (Kapp) and total

* *Electrical World*, 1920, vol. 76, p. 1021.

charge as 0·64 against 0·24. Even supposing the efficiency of the Metropolitan-Vickers machine to be 88·7 per cent instead of 87·7 per cent at $\frac{3}{4}$ load, the energy-loss figures would still be as 0·26 to 0·052, a very large difference. If, however, it were feasible to work on the lines indicated by the results of the tests on the 470-b.h.p. machine (taking the $\frac{3}{4}$ load figure), the interest and sinking fund charges would amount to only £0·026 per horse-power per annum, while the loss charge would be nil and, consequently, the total charge would be £0·026, which is roughly 1/14th of the full-load charge on the Metropolitan-Vickers motor and 1/25th of the $\frac{3}{4}$ load charge for the same motor. If $\frac{3}{4}$ load were the average load for the 470-h.p. machine, and if the additional 17 per cent output already alluded to could be obtained, we should have a margin of 50 per cent before the pull-out torque was reached. If the Yale University tests and my figures are correct, and results similar to these can be obtained at 160 b.h.p., it would appear as though an ordinary induction motor would be rather a tempting solution to the consumer. In the above tables the recovered kilovolt-amperes are given in the fourth column. I suggest that the costs per kilovolt-ampere recovered will not weigh with the consumer if he is merely given a rebate on the basis of bringing up his motor to a predetermined power factor. It will naturally not be to his interest to carry the rectification of the power factor any further, and in such a case the Kapp phase advancer is of considerable advantage on account of the much higher efficiency. If, however, central station engineers elect to give the consumer a progressive rebate without any limitation as to the amount of the power factor correction, there would of course be an inducement to install a machine with a higher range of power factor correction, as for example the Metropolitan-Vickers motors. In the latter case a smaller number of motors would have to be equipped in order to produce a given power factor rectification on the whole system. The central station engineer has to weigh up all these points in deciding on which policy he will adopt.

Load	Overall Efficiency including Excitation		Recovered kVA	Annual Charge per H.P.
	Ind. Motor	Syn. Motor		
10 *b.h.p.* (*Warner & Knowlton*).				
b.h.p.	Per cent	Per cent		Increase or Decrease
5	67	72	8·75	{ − 0·28 * } = £0·02
7½	75	79	8·20	{ 0·26 † }
10	78	80	5·71	{ − 0·28 * } = £0·15
				{ 0·13 † }
470 *b.h.p.* (*Birmingham*).				
235	92·5	89·5	248	—
352	92·5	92·5	243	{ 0·026 } = £0·026
				{ 0·000 ‡ }
470	92·0	94·5	229	{ − 0·026 } = £0·085
				{ − 0·111 ‡ } (gain)
160 *b.h.p.* (*Metropolitan-Vickers*).				
80	86·2	‡	‡	—
120	91·5	87·7	‡	{ 0·25 } = £0·64
				{ 0·39 ‡ }
160	90·7	89·7	155	{ 0·25 } = £0·38
				{ 0·13 ‡ }
160 *b.h.p.* (*Kapp*).				
80	91·5	90·9	‡	—
120	91·1	90·7	‡	{ 0·19 } = £0·24
				{ 0·05 ‡ }
160	90·7	90·2	69	{ 0·19 } = £0·25
				{ 0·06 ‡ }
160 *b.h.p.* (*Birmingham*).				
80	86·2	78·5	110	—
120	91·5	85·5	95	{ 0·039 } = £0·82
				{ 0·78 ‡ }
160	90·7	87·5	69	{ 0·039 } = £0·43
				{ 0·39 ‡ }

* Interest and sinking fund charge.
† Annual loss charge.
‡ Information wanted.

Mr. R. A. Chattock: The installation of synchronous induction motors on consumers' premises will cost the consumer roughly about 25 per cent more than the plain induction motor. The only benefit the consumer will obtain is in having to provide a slightly smaller transformer and cables. The question of what inducement can be offered to the consumer by the supply authority is now being considered, and it is very doubtful if a sufficient inducement can be offered. As a rule, the supply authority would correct its own power factor over a large portion of its supply, by means of synchronous plant in its own substations. This supply is chiefly through main trunk cables to the distributing centres; beyond these centres it may pay the supply authority to arrange for power factor correction where the distributing cables are of any great length. Where they are short, however, it is doubtful whether any special rebate can be justified. The operation of the synchronous induction motor appears to be more suitable from the supply point of view than the operation of a static condenser. With the latter apparatus, if the load is switched off and the condenser left in circuit at night, as is quite likely, it is possible that the power factor may be advanced to such a point that the supply may become unstable. This would not happen with the synchronous induction motor.

Professor W. Cramp: Among the advantages of synchronous induction motors claimed by the author that under par. (*d*) seems to me to be fallacious, since the conditions of commutation in the case of, say, the Kapp phase advancer, are at least as good as any that obtain in the case of any other type of machine. I should like to point out that the inverted machine would appear to be capable of being made self-exciting by the addition of special connections and a commutator to the rotating member. Perhaps the author can say if this has been done. The author says that the cross-hatched area of Fig. 2 gives the torque causing acceleration. This is incorrect, as the *ordinates*, not the *area*,

of this figure represent torque. The agreement between calculated and tested slip in the author's table is not very good. One reason for that, I think, is to be sought in the method of measuring the slip. It is difficult by stroboscopic methods to measure the slip to 0·01 per cent and I should be glad if the author would say how he contrived to do this. But these calculated figures, in common with many of the curves given in the paper, are deduced from approximate formulæ developed in the Appendix, of whose validity we must be assured before we accept the author's conclusions. It is a pity that so few confirmatory tests are included; and even where figures are quoted, as in the constants of the machine given in the Appendix, the information is too meagre to be of much use. But the very formulæ upon which the whole fabric of the paper rests are open to considerable doubt, if they are not actually wrong. Thus the formulæ for excitation would suggest that the exciting current possible is determined entirely by the overload capacity and the secondary open-circuit induction motor voltage, which is not correct when the machine is running as a synchronous motor. This error, however, is of minor importance when compared with those occurring in the derivation of the formulæ for limiting slip. For instance, in the list of symbols p is given as the number of pairs of poles, and $T_l = T_m \cos p\phi$. From the definition of α it must follow that p should also appear on the left-hand side of the torque equation. But is this even now correct? From the definition of α it would appear that the author thinks the synchronous torque is a maximum when $\alpha = 0$. This is most certainly wrong, for it is then zero. Indeed, the synchronous torque is much more probably $T_m \sin p\alpha$, or, for small angles, $T_m p\alpha$. The author's equation therefore must at least be corrected to

$$T_m \sin p\alpha = \frac{J}{\omega}\frac{d\alpha}{dt} - T_l = -J\frac{d^2\alpha}{dt^2}$$

But even this is not correct, as it assumes that the induction torque is not changed by opening the rotor and inserting the exciter armature, which is certainly wrong, so that a further coefficient less than unity (say m) must be introduced in the second term of the above modified equation, giving

$$T_m \sin p\alpha = \frac{J}{\omega}\frac{d\alpha}{dt} - T_l = -J\frac{d^2\alpha}{dt^2}$$

The author next says that his torque equation cannot be solved "by the usual mathematical methods." I do not know what he intends to include under this description, but I think he will find that if he puts $\alpha = t^n$ and chooses $n = 0$ and $n = 1$ with a solution of the form $\alpha = 1 + at + bt^2 + ct^3$, etc., he can solve this equation. It is perhaps tedious, and certainly not worth while to carry out the integration until he has agreed whether his form of equation or mine is the right one. Obviously the approximate form obtained by substituting $p\alpha$ for $\sin p\alpha$ is quite easily solved and would be sufficiently correct for values of α $\frac{1}{8}$ pole pitch in radians. I shall now deal with the author's approximate equation

$$J\frac{d^2\alpha}{dt^2} = T_m\frac{\phi}{\phi} - \frac{\alpha}{\phi}$$

I am at a loss to understand how he has arrived at this, and should be glad if he would explain. But granting that it is correct (which I do not believe) the solution he gives is firstly *not* a solution, and secondly is not even the first integral of the above. The solution of the above equation should give α, not $d\alpha/dt$. Now the value of $d\alpha/dt$ is, from direct integration,

$$\left(\frac{d\alpha}{dt}\right)^2 = -\frac{2T_m}{J}\left(\alpha - \frac{\alpha^2}{2\phi}\right) + \text{constant}$$

which has no apparent connection with the author's solution. It is therefore impossible to see how he has arrived at the final approximation

$$\omega = \sqrt{\left(\frac{1{\cdot}2\phi T_m}{J}\right)}$$

When on page 170 the power factor of 0·9 is specified, the author should say to what load this power factor refers, and, when he refers to the efficiency figure of the synchronous induction motor, it would be well to make clear whether the rotor excitation loss only is allowed for, or whether the losses also include those in the exciter itself.

Mr. F. J. Moffett: The question of power factor improvement is very urgent owing to the increase in the number and size of three-phase power installations, many of which show a power factor as low as 0·6. The synchronous induction motor possesses the valuable characteristic that it can not only run at unity power factor but deliver a leading component which is available for the correction of the power factor of the system. According to the paper it is not practicable to convert an existing induction motor to a synchronous machine without rewinding the rotor and providing extra slip-rings. This is a drawback. Major Taylor stated in his remarks that he had applied direct current to the excitation of the rotors of ordinary induction motors, but apparently this was only for test purposes. Previous speakers have assumed that in order to correct the power factor the only choice lies between the synchronous motor and the Kapp phase advancer. A third method is to use a static condenser, and a comparison as to prime cost with the synchronous motor may be of interest. Assume the cost of an induction motor absorbing 100 kW to be £750. According to the author the price of a synchronous induction motor would be £1 000, or an additional cost of £250. For this expenditure of £250 one would obtain a leading component of 48·5 kVA which would be available for the supply of magnetizing current to the rest of the system, so that the cost per kilovolt-ampere would be approximately £5. A static condenser with an output of 48·5 kVA would, on a 50-period system, cost about £220, or slightly less per kilovolt-ampere than the synchronous motor. To obtain a fair comparison with the motor, however, we must credit the latter with the kilovolt-amperes

it supplies for its own correction, as these would have to be supplied by the condensers if a plain-type machine were substituted. It would appear, therefore, that in the case under notice the capital cost of correcting by condensers is something approaching double that involved by the use of the synchronous induction motor, and the principal advantage to be derived from the use of the former would seem to lie in the increased efficiency with which the correcting kilovolt-amperes can be generated. The losses in the synchronous motor due to its being over-excited to give a leading power factor would be more than double those in the condenser, which are less than 0·5 per cent of its output. In many power installations of considerable size there are no motors exceeding 25 h.p., and these are too small to be of the synchronous type. In such cases the condenser is the only practical method of supplying the magnetizing current. A consumer will ask what advantage this power-factor-correction proposal will be to him. Unless the supply authority will give him some inducement to improve his power factor, it is very unlikely that he will take any steps in this direction, as usually the benefits to him are limited to increased capacity of transformers and distributing cables. I suggest that it is in the interests of all supply authorities to give an inducement in the form of a rebate or penalty, as the advantages to the supply are very much greater than those to the consumer.

Dr. G. Kapp: The fundamental fact that torque is proportional to the product of flux and current is stated on the first page of the paper. As far as the induction motor is concerned, where saturation does not materially alter the proportionality of flux and current, the torque may also be considered to be proportional to the product of the power components of stator and rotor currents, but in the synchronous type of motor this no longer holds good in regard to ampere-turns. Here it is more in accordance with the physical condition if we consider the torque as depending on the flux emanating from the rotor and the ampere-turns in the stator. Now it is clear that within the heating limit it is possible that by stronger direct-current excitation we can shift the working point higher up on the characteristic and thus obtain more torque, but not in proportion to the increase in exciting current, because the characteristic in that region becomes flatter. The author states that if the motor falls out of step whilst working synchronously it will not stall, but will continue to run as an asynchronous motor. I find it difficult to agree to this. The fact that the motor is worked highly over-excited and has a strong and stiff field ensures a strong torque. If the load torque is so large that the motor falls out of step it is difficult to see how the torque given by the motor when it has become an induction motor can cause it to fall into step again. In the circle diagram the stalling torque is limited by the radius of the locus circle. This, however, is reduced by the effect of added inductance in the phase which contains the direct-current armature of the exciter. This is also the condition at starting, and it follows that the maximum starting torque is smaller than the stalling torque of the motor when working as an ordinary induction motor not encumbered by added inductance in one of its rotor phases. When we are told that the motor has from 2 to $2\frac{1}{2}$ times normal working torque at starting, this increase cannot be due to its ability of changing into a synchronous motor. It is simply due to its inherent ability to give such a large stalling torque as a plain induction motor. Now it is well known that the ordinary commercial motor will stall at about 75 per cent overload. If then the claim to start against 100 to 150 per cent overload is to be substantiated, a special motor designed on very liberal lines must be used. Naturally this will be more expensive and I should like to know how the excess cost of 30 per cent is divided between the enlargement of the motor itself and the added cost of the exciter. The reduction of the diameter of the locus circle due to added inductance is an important point with all phase advancers, and this matter could easily be investigated as follows. Insert an inductance representing the exciter armature into the lead connecting one slip-ring to the starter and provide for it a short-circuiting switch which is closed during starting. Load the motor by letting it drive a generator. Then with the switch still closed load the generator up until the circuit breaker comes out. Then start again and when up to speed open the switch and again gradually load up the generator until the circuit breaker comes out. The record of the two loads at which the motor stalled will give the reduction in the diameter of the locus circle. Any of the well-known methods for finding the locus circle without running under load can, of course, also be used. By putting the added inductance into all three leads the investigation could also be made useful for phase advancers of other types. It would have added to the value of the paper if the author had given in confirmation of some of his statements actual figures from test. I should like to give some figures from an article in the *Westinghouse Journal* for June 1918. These figures concern a 300-kW, 10-pole motor giving 330 kVA with a leading power factor of 0·9. The open-circuit slip-ring pressure is 1 200 volts and working as an ordinary induction motor the rotor current is 168 amperes. When working synchronously the rotor current is 400 amperes supplied by the exciter at 30 volts. We find that the total ampere-turns in the two cases are in the ratio of 1 to 1·68. For equal heating the rotor must contain 2·8 times more copper in the synchronous induction motor than that which suffices in the plain induction motor. This is rather a serious increase in cost, but possibly some improvements have been made since then and I should be glad to know whether this is the case. In this 300-kW motor the excitation accounts for 12 kW, i.e. 4 per cent of the output. If a 300-kW motor were provided with a vibrator the excitation of this apparatus would require a supply of only 500 watts, whilst its own losses would be covered by the saving in stator copper heat, and at unity power factor there would be only an inappreciable increase in the rotor copper heat. We have, therefore, at unity power factor practically the same overall efficiency whether a vibrator is used or not. With a synchronous induction motor the overall efficiency is stated by the author to be only 1 per cent

less than with the ordinary induction motor. With a power factor of 0·9 leading there is practically no saving in stator copper heat, so that the 12 kW of exciting power quoted above represents rotor copper heat. If we allow 0·9 for the efficiency of the exciter we must allow not 4, but 4·4 per cent, minus slip (say 1 per cent), or, say, a reduction of 3·4 per cent in the overall efficiency of the synchronous induction machine. How does the author reconcile this calculation with his statement that the efficiency is lowered by only 1 per cent? The machine has, however, the advantage of a negative value of $\sin\phi$, and this may be obtained at the cost of about 14 kW. Since the excitation of the exciting generator is kept unaltered the energy efficiency will, owing to lighter load periods, be reduced by more than 3·4 per cent and the number of leading kVA-hours over the whole working time will be increased. The latter may be an advantage if the problem is to improve the power factor of a common network. In Fig. 10 a spiral line is shown but not explained in the text. Fig. 15 (*b*) represents the starter given in the Westinghouse publication already mentioned. It requires only one switch. The other diagrams show arrangements for larger motors requiring three switches, and in one case four. Considering that these switches have to carry large currents the switchgear becomes rather a formidable affair and I should like to know why with a motor having an open-circuit slip-ring pressure of 1 200 volts one switch is sufficient, while three are used with 2 000 volts. Finally, I should like some information as to flashing on the switch contacts when the rotor current is momentarily broken due to switching over to synchronous working.

Mr. L. H. A. Carr (*in reply*): I wish to deal first with the point that Mr. Jakeman has raised, viz. to what is the difference between the results obtained by Dr. Rosenberg and myself due? Rosenberg begins by dealing with an unloaded machine and takes the average synchronous torque to be equal to $2/\pi$ times the maximum value. This means to say that he has taken the time average to be the same as the space average. Since the speed of the rotor is varying and since its speed relative to the synchronously rotating field, that is to say the slip, is varying within wide limits, it does not necessarily follow that this is true, and Dr. Rosenberg makes no attempt to show that it is so. But further, I disagree entirely with Rosenberg's statement that: "The limit of slip which still allows pulling into synchronism is therefore nearly the same in a machine which under a certain load runs up on its own squirrel cage as in an unloaded machine with no squirrel cage which is brought up to the same slip by means of an outside motor." I disagree with the proof of this because Rosenberg has added up as time vectors the two curves of torque. The curves are not sine curves, neither do their principal axes move at a constant velocity. Time is not proportional to displacement; in fact, in the critical case the displacement is finite and the time is infinite. A further reason for my disagreement with the statement quoted above is that, if the actual curve obtained for the critical case by step-by-step methods (my Fig. 11) be examined, it is clearly seen that if curve C be prolonged backwards, the amplitude of the torque producing the oscillation is greater than the amplitude of the synchronous torque. I am indebted to Mr. Jakeman for bringing forward the fact that Rosenberg's expression for the limiting slip can be reduced to a form very similar to that which I have used. This transformation had previously escaped me. Mr. Jakeman criticizes Fig. 2, saying that Rosenberg has pointed out that the mean speed is not passed through when the synchronous torque is a maximum. Although this statement was made by Rosenberg, a reference to his original paper shows that it does not bear the interpretation which Mr. Jakeman has put on it. Rosenberg in making this statement referred to an oscillation where no induction torque was present, but only synchronous torque, and his statement expressed in more general terms clearly means: "The mean speed is not passed through when the torque causing the oscillation is a maximum." This is exactly what Fig. 2 in my paper shows. The mean speed is *not* passed through when the total accelerating torque is a maximum, but later, that is, when the synchronous torque alone is a maximum. This consideration upsets Mr. Jakeman's proof for the limiting slip, and indicates that his results will be too high, since his integration starts too early and covers too great an area on the torque curve. Further, as I have pointed out with reference to Rosenberg's results, I do not agree that the method of adding T_s and T_i vectorially is correct: t_s does not follow a sine law in time, while t_{ia} follows a sine law neither in time nor in space, and Fig. E is in error in this respect. As Fig. 11 in my paper shows, t_{ia} in the critical case gives almost a straight line when plotted as a function of the displacement "α."

Mr. Jakeman and Prof. Cramp have both pointed out a 90-degree error in the definition of "α" in the Appendix in the advance copies of the paper, and this error has been corrected in the paper as published in the *Journal*.

Prof. Cramp also objects to the fact that the fundamental expression for the movement of the rotor relative to synchronism was originally given as for a 2-pole machine. In deference to his opinion, I have revised this for "p" pole-pairs in the *Journal*. The revised expression as given by Prof. Cramp in the discussion is, however, wrong. In the second term the "p" which he has inserted should be omitted, as by definition this term equals T_i when $d\alpha/dt = \omega$. The insertion of an extra factor "m" differing from unity by not more than some 2 per cent is a needless refinement when dealing with fundamental theory, and, as pointed out by Mr. Jakeman, its effect may for all practical purposes be neglected. Prof. Cramp thinks that a complete solution of the differential equation referred to could be found by the use of a series. This is probably quite true, but so large an amount of work would be necessary, first to obtain a series that was definitely convergent, and secondly to obtain a single solution from this series, that this method cannot be classed among the "usual mathematical methods," at any rate from the point of view of the commercial designer. The substitution of p for $\sin pa$ has been used in the paper in one instance,

that is to say, in the "dying away" part of the curve in Fig. 9, after the second time of passing through synchronous speed, but for the sustained oscillation, where $p\alpha$ varies from zero to 2π, this simplification cannot be adopted. Similarly in the critical case, this substitution cannot be justified. Prof. Cramp cannot understand my simplified equation

$$-I\frac{d^2\alpha}{dt^2} = T_m\frac{\phi}{\phi_0}\alpha$$

As stated in the Appendix, this expression is designed to represent the case if the total accelerating torque, that is to say, the difference between curves C and D in Fig. 11, followed a straight-line law with reference to α. Since under these circumstances, at

$$\alpha = 0, \text{ torque} = T_m$$
$$\alpha = \phi, \text{ torque} = 0$$

the straight-line law must necessarily be $T_m\phi - \alpha T_m\phi$. Surely this needs no further explanation? Prof. Cramp states that my result for $d\alpha/dt$ is neither a solution nor even the first integral of the expression I have just written. I am sorry to have to disagree with him, but my results are most certainly correct. I had thought that it was quite well known that where a second differential coefficient of a dependent variable was equal to either the dependant variable itself or to a linear function of the dependant variable, the solution was always exponential in character, including in this description the variant forms of the trigonometrical and hyperbolical functions. Knowing this, the further step of integrating $d\alpha/dt$ would be quite simple. However, since this fact seems to be not so generally known as I had thought, I have inserted in the revised paper the value for α. It is then most elementary work to check back my result by differentiating twice and performing the necessary substitution.

However, let us take Prof. Cramp's own solution, and expand it. This solution, if the constant be put inside the bracket for convenience, reads:

$$\left(\frac{d\alpha}{dt}\right)^2 = \frac{2T_m}{I}\left(\alpha - \frac{\alpha^2}{2\phi} + C\right)$$

But when $\alpha = \phi$, $d\alpha/dt = 0$

Therefore $C = -\frac{1}{2}\phi$

that is $C = -\frac{1}{2}\phi$

Hence $\left(\frac{d\alpha}{dt}\right)^2 = \frac{2T_m}{I}\left(\alpha - \frac{\alpha^2}{2\phi} - \frac{1}{2}\phi\right)$

But where $\alpha = 0$, by definition $d\alpha/dt = \omega$

Hence $\omega^2 = \frac{2T_m}{I}\left(0 - 0 - \frac{1}{2}\phi\right)$

$$\omega = \sqrt{\frac{T_m\phi}{I}}$$

The above transformation shows that Prof. Cramp's solution is really identically the same as the one given in the paper, but calculated in a rather more roundabout manner.

To turn from the mathematical to the more general part of the discussion, I cannot agree with Dr. Kahn's statement that the synchronizing current of a synchronous induction motor must reach at least twice the full-load value; in fact, I have oscillograms which show that in some cases it rises only some 20 to 25 per cent above full-load current. Possibly, however, his remarks are only meant to cover the critical case, for which his statement is probably approximately correct, though I do not quite agree with his proof. Dr. Kahn also suggests that with the phase advancer the throw-over switch may be omitted. This is not true of all advancers. The Scherbius type is usually cut out at starting, since below 50 per cent slip it "retards" the phase instead of advancing it. I do not agree that the Kapp vibrator is a direct-current machine. I grant that the periodicity is low, but it is a low-voltage large-current a.c. machine nevertheless.

As Mr. Jakeman points out, the excitation formulæ given in the paper are not used in practice to determine the excitation current. This is calculated from the magnetization curve of the machine in the usual manner. At the same time these equations are useful in that they indicate both to the designer and to the customer the limits of excitation which are possible.

I must also reiterate, in particular reply to Prof. Cramp, that having decided on the type of secondary winding to be adopted (number of phases, connections, etc.), the exciting current is determined solely by the overload capacity and the secondary open-circuit induced voltage, and if when the machine is designed with that open-circuit voltage the exciting current is found to come out higher than was estimated by the above calculation, it will be found that the overload capacity has been correspondingly increased. The only error in these formulæ is that any difference in efficiency between full load and the pull-out point has not been taken into account.

With reference to the test results given in the paper, these were obtained on an ordinary works test plate, where the high accuracy desirable for research investigations is usually unattainable. Further, there must be some tendency, however slight, for the generator to swing down to the motor, as well as for the motor to swing up to the generator, and, since any switching effects tend to add up in the same direction, it is to be expected that the limiting slip measured on test should come out rather higher than the theoretical value.

In connection with the switchgear arrangements, Fig. 15 (*b*) is obviously restricted to relatively low voltages. With high voltages the 3-pole isolating switch is used as shown in Figs. 15 (*c*) and 15 (*d*).

I regret that although this type of machine has been commercially manufactured in this country for 13 or 14 years, Major Taylor should have waited to experiment with synchronous induction motors until he saw a note in an American publication. I would refer Major Taylor to the bibliography given at the end of the paper on page 174. I would also suggest to him that consumers frequently have more than one motor; hence a leading power factor on one machine would be of service to them in raising the power factor of their whole installation, without necessarily raising the question of rebates for leading power factors.

In further reply to Prof. Crampt it is probably feasible to make an "inverted" machine self exciting, though the disadvantages would probably outweigh the advantages in a commercial machine. This arrangement has been suggested by J. K. Kostko in an article entitled "Self-exciting Synchronous Motors" in the *Electrical World*, 1920, vol. 75, p. 723.

Wherever in my paper a motor has been referred to as being of a certain power factor, this power factor always refers to full load, and in the case of a synchronous induction motor is a leading power factor if the figure is fractional. Efficiencies are calculated on the basis of (useful shaft horse-power)/(electrical input), and, since each machine drives its own exciter, all exciter and rheostatic losses are thus included.

With reference to Mr. Moffett's remarks, it is possible to convert an induction motor to a synchronous induction motor without rewinding the rotor, by the simple provision of an exciter; in fact this has been done, but, as Major Taylor has pointed out, the full-load rating of the machine has to be decreased on account of the overload capacity.

Dr. Kapp asks how it is that a synchronous induction motor will continue to run as an induction motor after it has fallen out of step as a synchronous machine. This is simply a question of the design constants of the machine, which cause it to have a larger pull-out torque as an induction motor than as a synchronous motor. The reason for this will be clearer if I refer first to the later portion of Dr. Kapp's remarks about efficiency. A synchronous induction motor is usually larger than the corresponding induction motor. It has a larger d^2l. The magnetic loading and the flux densities are kept up to normal values, but the ampere-wires are reduced below the usual induction-motor value. This explains, first, why the reduction in efficiency is not so great as Dr. Kapp suggests, and secondly, why the pull-out torque as an induction motor is greater than the synchronous pull-out torque. Or conversely, let us consider a normal induction motor supplied with an exciter to work synchronously. The synchronous pull-out torque which depends on the excitation is, on account of heating limits, not much in excess of the full-load torque as an induction motor. Here it is quite clear that the induction-pull-out torque must be greater than the synchronous pull-out torque, though it must be admitted that the resulting design is not quite the same as if the machine were originally designed for synchronous induction operation. The above explanation also shows why the average synchronous induction motor will start from rest against 2 to $2\frac{1}{2}$ times full-load torque.

Experimental proof that the induction pull-out torque is greater than the synchronous pull-out torque is quite easy to obtain on test. If a synchronous induction motor be coupled to a direct-current generator (which forms a combination with relatively low inertia) and arranged to drive it at a certain load, a critical excitation for the synchronous induction motor can be found where, by diminishing it ever so slightly, the machine falls out of step into the induction-motor condition, with fluctuating current since the exciter is still in circuit with the rotor. If the excitation is then increased to its original value, the machine pulls back into step and runs again as a synchronous machine. I have carried out this test with a number of machines, but cannot see that a string of figures giving the loads and excitations at which the phenomenon occurred on a number of different machines, would have been of material value in the paper.

Dr. Kapp appears to find difficulty in following the curve shown in Fig. 10. I would refer him to my reply to the discussion at the Institution where this curve is referred to in more detail. The difference between a single-pole and a 3-pole switch in the rotor circuit is simply that the latter completely isolates the exciter during the starting period, and is therefore more suitable for high voltages. When switching over from induction operation to synchronous operation no flashing is experienced, the break being absolutely black in the majority of cases, though I have occasionally seen a microscopical pin-point of spark.

SOME NOTES ON THE DESIGN OF LIQUID RHEOSTATS.

By W. Wilson, B.E., M.Sc., Associate Member.

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Summary.

The paper has for its object the more definite determination of the constants of the liquid rheostat, and the more exact prediction of its performance.

First, the phenomena occurring in such a rheostat under a wide variety of circumstances are considered, a distinction being drawn between the behaviour of direct and of alternating currents in the apparatus. Tests are described which bear out and amplify the conclusions, many of which are characterized by the employment, with impunity, of current densities many times larger than those generally considered to fall within the limits of safety.

Representative designs of rheostats, for both small and large horse-powers, are described and criticized.

A mathematical method is developed for conveniently arriving at the capacity of a given liquid starter, from thermal considerations, which form the deciding factor in this case. A more elaborate calculation is also given, capable of more general application.

The effecting of artificial cooling for liquid controllers is dealt with, descriptions of the pipe-cooled and the adjustable weir types being included.

The functions of a liquid slip-regulator are analysed and the usual pattern is reviewed, the conclusion being reached that it could be simplified with considerable advantage.

Finally, suggestions are made with regard to specifications for governing the design and construction of this apparatus.

Introduction.

The liquid rheostat is playing an increasingly important part in the operation of electric motors, especially those of large capacity and those working on alternating-current mains. The smoothness of its control; its robustness, amounting almost to indestructibility; the facility with which its resistance can be varied within wide limits by modifying the strength of the electrolyte; its cheapness and ease of construction; and other minor qualifications, all combine to render it a valuable piece of equipment. To-day, when electric motors of ever-increasing capacity are being used in our heavy industries, dependent almost without exception upon this type of rheostat for their control, its design is becoming more and more important.

When this apparatus was first employed it was regarded as being useful only as a temporary piece of plant, chiefly owing to the unstable nature of the material used for the resistance. The water was apt to diminish in quantity by evaporation, and the strength of the liquid was liable to change through the same cause; while electrolysis caused both plates and electrolyte to become foul and deteriorate. The liquid might boil and so give rise to dangerous fluctuations of current, with the risk of entire breakdown due to arcing. Even when at rest it usually deteriorated owing to corrosion. These defects have, however, been almost entirely overcome in modern designs, and the liquid rheostat now possesses an assured place in the electrical industry. Once its position became established, the standardization of its design followed, and it has been found possible to treat the design of this form of resistance as mathematically as that of the metallic type.

During the past few years, the author has made a number of tests and experiments, with a view to ascertaining the constants necessary for the design of this apparatus, and the more important of the results are contained in this paper.

The principal information desired was that which enabled the limits of rating to be ascertained. Not only did the maximum practicable current density require examination, but it was necessary to discover the number of times a given liquid controller could be operated in a given period. A method of calculation was evolved which appeared to be sufficiently reliable and convenient to justify a description being given in this paper. To these have been added various items of general design, including the question of artificial cooling, and a discussion on the designs of the principal types now in existence. Reference is made to the chief uses to which liquid rheostats are put, including the slip-regulator for large motor-generator sets employing the Ilgner method of control, and to the possibilities for the future.

Need for Investigation.

In common with the majority of apparatus, the liquid controller was first designed on the basis of the performance of models, whose proportions were arrived at largely by guesswork. Satisfactory working results having been obtained from these, safe dimensions were fixed for rheostats of various capacities, a generous allowance being usually made to cover contingencies.

Thus a few models were standardized by each manufacturer, and these were usually made to do duty at their rated capacity for alternating or direct current indiscriminately. The amount of experimental work devoted to them does not appear to have been great; in particular, tests to destruction seem to have been omitted. The liquid rheostats in use all fulfilled their functions without giving trouble, at least as far as their dimensions were concerned, and no special effort was customary to find out more exactly what each piece of apparatus was capable of doing.

This rather chaotic state of things can be gauged by

a perusal of the rules for liquid-rheostat design as given in the various handbooks, etc., dealing with this subject. Almost the only detail usually supplied is the permissible current density, expressed in amperes per square foot of electrode surface; and the various estimates for this differ widely from one another. Thus various authorities limit this value to 400, 144, 100; and even as low as 30 to 40. In scarcely any instance that has come to the author's notice has any distinction been made according to whether the current was direct or alternating. One writer upon the design of rheostats for alternating current refers to the "violent gassing" as well as steaming that was to be guarded against, although this phenomenon should occur with direct current only.

Again, the rules for the spacing of the electrodes have been variously given. Some writers give curves for calculating the separation per volt for various strengths of various electrolytes, from which is usually omitted, however, that containing washing soda, the one most used in practice. On the other hand, statements are sometimes made that the spacing has little effect upon the load capacity, but that most of the resistance is met with at the surface of the plates.

Thus it seems that not very long ago there was a conflict of opinions which could be settled by an experimental and analytical inquiry into the whole subject from first principles.

Action of the Liquid Rheostat.

In order to arrive at an estimate of the factors that limit the duty to be obtained from a given liquid rheostat, it is necessary to consider the various phenomena that take place when a current is passed through an electrolyte. These may be dealt with under three headings, namely:

(1) Thermal phenomena.
(2) Chemical phenomena.
(3) Other phenomena.

The last group includes any that may be present to a less marked degree than the first two, and that may possibly be masked by the effects of these.

(1) *Thermal phenomena.*—The effect of the electric current which is common to all rheostats whether solid or liquid, and which occurs with all varieties of current, both direct and alternating, is that whereby heat is generated in the resisting material. The capacity of a wire-wound resistance unit is limited by the temperature to which it can be raised with impunity. If the limit is overstepped, the coils will fail by fusing or softening, or by becoming brittle; but in any case a breakdown is the result. With a liquid resistance the result is ebullition, the harmful effects of which disappear when the temperature falls again. This is an advantage.

On the other hand, the safe limit of temperature of the metallic resistance is much higher than the boiling point of water, and it is possible to obtain a relatively greater cooling surface than is the case with the corresponding liquid resistance. This means that the former is able to get rid of its heat more readily than the latter, and that, therefore, the solid rheostat should be naturally adapted for a more frequent succession of operations than the liquid rheostat, unless especial attention has been given to the question of cooling.

The quantity of heat produced in a liquid varies with the number of watts dissipated. Thus the rise in temperature is dependent, not only on the current flowing, but also on the fall of potential between the electrodes.

(2) *Chemical phenomena.*—In contradistinction to the heating effect, the magnitude of the chemical effect varies with the current only, and is independent of the potential absorbed in the rheostat. This is the direct consequence of the law which states that a chemical change always accompanies the passage of an electric current through a compound liquid. The practical results, as far as rheostats are concerned, are as follows:—

(*a*) The electrolyte itself is decomposed, so that in general it deteriorates with use. The exceptions to this are found in a few cases that are not employed to any great extent for the purpose under discussion. In these the action at one plate is exactly counteracted by a reverse action at the other. Examples are seen in the rheostat composed of lead–sulphuric acid–lead; and that consisting of copper–copper sulphate–copper.

(*b*) One plate, the anode, is eaten away. Except in the two cases that have just been quoted, the material so eroded fouls the liquid. In the first case the combination undergoes the same reactions as the lead accumulator, while in the second case, copper is removed from the anode and added to the cathode, thus constituting a species of plating bath. In most instances met with in practice, however, the result is that both anode and liquid undergo more or less serious deterioration when in active use with direct current.

(*c*) Gas is generally given off at the plates, appearing as bubbles of varying size, depending partly on the density of the current per unit area of electrode. This gas is usually derived from the decomposition of water, and bubbles of hydrogen predominate. When gassing is excessive, one bubble may extend from plate to plate, and spontaneous ignition, or an explosion on a small scale, is then possible. If the production of gas is permitted to increase, these large bubbles eventually set up a sub-aqueous arc between the plates, and thus form practically a dead short-circuit across the rheostat.

An objection to solutions of common salt for use in rheostats is that chlorine may be given off in sufficient quantity to endanger human life. The gases from sulphuric acid electrolytes are also objectionable.

The peculiarity of all electrolytic phenomena is that they are undirectional, i.e. they are reversed if the direction of the current reverses. Hence it would be expected that the effects of electrolysis would be very much less, or even absent altogether, with alternating currents. In practice these effects are found to be negligible with alternating current under ordinary conditions. Tests giving definite results in this regard are described later in the paper. Even when electrolysis is absent, a certain small amount of chemical action occurs between the plates and the liquid, chiefly of the nature of rusting. In nearly every practical appara-

tus, iron electrodes are employed, and one of the following electrolytes :—

Sodium carbonate (washing soda) ;
Sodium chloride (common salt) ; or
Sodium hydrate (caustic soda).

Of these, the second has by far the greatest corrosive effect upon the iron, and the other two are therefore preferable, but these have the property of disintegrating almost all plastic insulators such as varnish, cement, wax, etc., and they also exercise a deteriorating effect upon pottery. Most standard designs, however, do not suffer to any serious extent from corrosion by the carbonate or hydrate.

(3) *Other phenomena.*—The two classes of phenomena already mentioned account for all the effects that are manifest in ordinary practical apparatus working at the usual current densities, not exceeding, say, 400 amperes per square foot. As the author intends to consider the use of much higher densities than these, there is a possibility of other phenomena making their appearance under these altered conditions, especially when the overpowering effects of the usual well-marked phenomena have been to a large extent eliminated. Electromagnetic effects are sometimes intentionally present in electrolytic tanks, but need a magnetic field for their production. Both these and statical phenomena are scarcely possible in the present case. The only other that seemed available was the Wehnelt effect, and this in particular was watched for. As described later, however, no new phenomena apart from those mentioned in sections (1) and (2) were observed.

Limits to the Capacity of Liquid Rheostats.

A wire-wound rheostat has a well-defined limit beyond which it cannot be used without serious risk of breakdown. For example, a 10-h.p. motor starter cannot be used for a 20-h.p. motor without incurring the danger of deforming or fusing its resistance coils. In this the limit is set by the rigidity and resistance to softening of the metal employed as its melting point is approached. With a liquid resistance material the limiting conditions are not so simple, for all the phenomena that have been mentioned in pars. (1) and (2) above contribute towards the restriction of duty of a given apparatus. Some of these may not be present in certain cases ; while it may be practicable by suitable design to do away with others, either wholly or partially. Thus it is not possible to lay down a general rule that in every case the current density must be a certain value, or the total watts absorbed so much.

Again, a rheostat must be able at certain specified intervals to repeat the operation for which it is designed without sustaining damage, and it must be able to continue in service for a given period without receiving more than ordinary attention. These features cannot be predetermined without an exact knowledge, based on theory and experiment, as to the behaviour and constants of the apparatus. With this end in view, the author proposes to describe some tests and calculations having for their object the estimation of these particulars.

Tests to Investigate the Limit of Current Density.

It was first desired to find whether there was an limiting circumstance, other than the effects enume ated in divisions (*a*) and (*b*) above, which would rende impracticable current densities up to, say, 5 000 ampere per square foot. To accomplish this, an endeavou was made to obviate as far as possible the known effect and in their absence to watch for the existence of an others. Of the former, the three most troublesome ar those due to chemical action, and, as has already bee mentioned, there was at the outset every hope of thi being almost, or quite, non-existent with alternatin currents. For the first tests, illustrated by Figs. 1 t 4, this form of current was therefore employed, at frequency of approximately 25 cycles per second.

The next problem was to avoid all possible disturb ance due to the generation of heat. This was accom plished in the apparatus shown in Fig. 1, in which tw small iron electrodes, 2 inches square, were situate not far from the bottom of a glass-sided tank. Al metal parts, including the backs and edges of th electrodes, were protected by insulation, and thu

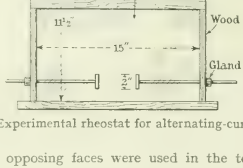


Fig. 1.—Experimental rheostat for alternating-current tests

only the opposing faces were used in the test. The apparatus was designed to permit a close inspection of these faces. As it was important that the liquid should remain clear during the tests, common salt which has no action upon the insulating materials present, was used as the electrolyte in the form of a 5 per cent solution.

With this apparatus, current densities up to 4 750 amperes per square foot, obtained from 132 amperes at 24 volts, were passed through 0·25 inch of electrolyte without giving rise to any appreciable phenomena except the evolution of heat. It would, in fact, have been impossible to tell by mere inspection of the closest description, whether the current was flowing or not, except for a slight, yet visible, effect. A minute quantity of gas ascended from the plates at the beginning of the test, and considerably decreased as the experiment proceeded. From the latter circumstance, the gas was conjectured to be atmospheric air driven out of solution by the heat. This was the only visible effect of the current-flow.

After currents of varying magnitude had been passing for about an hour, the electrodes were taken out and examined. Except that they seemed to have been cleaned by the process they had undergone, and that a very small quantity of dark-grey powder was adhering to their surfaces, they appeared unaffected. It can thus be safely concluded that at high current densities,

i.e. up to 4 750 amperes per square foot, there is no appreciable amount of electrolysis or other phenomenon than that of the production of heat.

An extension of the above test was rendered possible by the use of a larger alternator. The current density was now ultimately increased to 11 880 amperes per square foot, obtained from 384 amperes at 91 volts across the 0·25 inch of solution between the electrodes. Much more energetic phenomena were observed, the sequence of events being as follows :—

At a density of 4 220 amperes per square foot, the current passed through the liquid quietly and very little gas was given off. Upon the density being increased to 5 870, at 45 volts, somewhat more gas reached the surface, although the amount was still inconsiderable. Steam bubbles, however, were seen to form between the electrodes, but were quickly condensed. At 7 080 density, steam was rapidly forming, but still condensed before it occupied any great proportion of the total space between the electrodes. At 10 640, the production of steam had still further increased, and the faces of the electrodes were dotted with small arcs, not much bigger than a pin head, which appeared and disappeared suddenly. The potential difference across the space was now 80 volts.

Finally, at 91 volts, a density of 11 880 was reached. Small explosions between the electrodes had begun since the last reading, and these now became vigorous, causing considerable disturbance of the liquid. The production of steam was violent and continuous, and this did not condense until it had reached about half-way to the surface.

Although it was evident from the yellow colour of the liquid that chlorine was being given off, none of this gas reached the surface of the liquid. The circulation and vibration of the liquid were becoming serious, and the glass of the tank showed signs that it would not be able to withstand much more of this treatment. The current was nevertheless kept flowing at this rate for 3 or 4 minutes, and the test was then discontinued.

In spite of the sensational character of the phenomena described above, which apparently favoured a breakdown through arcing, this did not occur, and therefore no upper limit has yet been found for the current density. As, however, the first signs of any occurrence other than heating and very slight gas production were evidenced after 10 000 amperes per square foot had been passed, this density may be recommended as a conservative safe limit for this type of apparatus.

No statement that has been made above is meant to suggest that electrolysis does not take place to a considerably greater extent than is indicated by the tests, but it is shown that the ultimate effects are negligible in practice. There must be quite a considerable chemical change produced during any given half-period at these high current densities, the effects of which are exactly reversed during the succeeding half-period, if, as in this case, the nature of the solution and other attendant conditions are favourable. In the following test it will be observed that the latter was not altogether the case.

The effect of a high current density having been dealt with, conditions were now modified to introduce a high voltage gradient. Plain water was used in the tank, and the electrodes were adjusted to a separation of $\frac{1}{4}$ inch. The pressure was increased to 600 volts, giving a gradient of 2 400 volts per inch, and a current passed of 14 amperes, or 504 amperes per square foot. Large bubbles of steam were produced by the 8·4 kW acting on the small volume of liquid between the plates; but although the power was supplied for some time, there was no sign of breakdown, and the closest inspection failed to reveal any arcing or other troublesome phenomenon.

It was observed that a small proportion of the bubbles evolved reached the surface of the liquid, and their amount was increased by reducing the separation of the plates to $\frac{1}{8}$ inch. With 8 amperes passing at approximately 220 volts, conditions were favourable to the collection of a small test-tube of explosive gases, in about 5 minutes. This gas was undoubtedly due to the electrolytic decomposition of water, but the extent of the action was still far from being serious. In

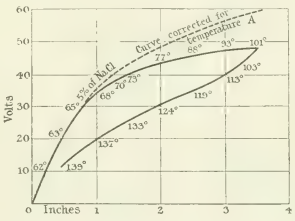


FIG. 2.—Variation of voltage-drop with spacing on experimental rheostat. Density : 2 000 amperes per square foot.

addition, the electrolytes employed in practice very rarely consist of other than alkaline solutions. Of these, sodium bicarbonate is the only example which has, in the author's experience, caused the evolution of gas to the above extent.

Using the same apparatus, a further test bearing upon the ultimate capacity was carried out, the electrolyte again being a 5 per cent solution of common salt. The object of this was to search for any surface effect of the nature of the "surface contact resistance" that has been alleged to account for much of the resistance in the apparatus. Keeping the current density constant, the separation of the plates was varied by steps of $\frac{1}{16}$ inch, and the voltage-drop across the rheostat was plotted at each point. No attempt was made to keep the temperature constant, but values of the voltage were obtained for both ascending and descending values of the spacing, and thus a constant temperature curve was easily deduced. This is shown in Fig. 2 (curve A), the lower curve being obtained experimentally.

This result shows almost conclusively that there is no surface effect; for the curve is practically a straight line from the origin to at least a point representing $\frac{1}{2}$ inch of spacing, or 25 per cent of the linear dimensions

of the electrodes. The bending-over of the curve after this point is due to the virtual enlargement of the area of the liquid "conductor," caused by "fringing" of the lines of flow.

It was thought advisable to make this experiment quite conclusive, by eliminating the effects of fringing and temperature. It is well known that when a larger copy is made of such a small model, phenomena that are comparatively unimportant may be magnified and

FIG. 3.—Experimental tubular rheostat.

may become predominant. If, therefore, it could be proved that there was no surface effect whatever in the small apparatus, it could be much more safely concluded that none existed in the larger one. Accordingly, the rheostat shown in Fig. 3 was constructed, the cylindrical portion being a glass tube. From it the curve shown in Fig. 4 was obtained, and this is an

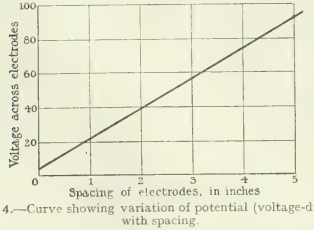


FIG. 4.—Curve showing variation of potential (voltage-drop) with spacing.

exactly straight line. The small voltage existing at zero separation was actually recorded on the meter with the plates in contact, and was apparently due to an accidental resistance in the current leads. In this case the temperature was kept constant throughout, and a current density of 540 amperes per square foot was employed.

Thus it can be concluded that with alternating current and the usual electrolytes, chemical effects are negligible, and that all the resistance is due to the electrolyte. The first of these facts simplifies the problem of designing a liquid rheostat for use with alternating currents, for it proves that the evolution of heat is the only phenomenon to be reckoned with. Given the necessary facilities for the removal of the latter, current densities can be employed at least of the order of 6 000 to 7 000 amperes per square foot, and probably higher if it should prove desirable.

Some of the above conclusions were confirmed by tests upon a larger apparatus, using electrodes about 17 inches square. In this case much higher voltages and powers were employed. In one test a potential of 500 volts was maintained across $3\frac{1}{8}$ inches of tap water, giving 187 amperes, or a total of 93·5 kW. In another, 580 amperes at 172 volts, a total of 100 kW were passed through 5 inches of a weak solution of washing soda. There was no trace of arcing or gassing, although the passage of the current was maintained until the liquid boiled. The boiling took place somewhat quickly, as there were no special cooling or circulating arrangements.

These tests finally dispose of the alleged surface effect, as far as the conditions of the commercial liquid rheostat are concerned. There is no doubt, however, as to the existence of a high surface resistance under special circumstances, such as those sometimes encountered when temporary rheostats are set up for the testing of large generators. For this purpose, small electrodes, such as iron pipes, are partly immersed in plain water. The portions below the surface of the liquid are apparently surrounded by a "blanket" of steam which, owing to poor circulation, is not readily dissipated.

It is not quite certain to what causes this "blanketing" is due. When it occurs, the portions of the pipes below the liquid appear red-hot, and the resistance fluctuates over wide limits. A potential of the order of 5 000 volts is one of the conditions of such tests, and the trouble seems to disappear for lower pressures. But such conditions are not encountered in the case of the apparatus described in this paper; nevertheless confusion has been caused in the past through designers generalizing on the strength of such results.

It will be observed that no limit for current density has yet been found. The cause of such breakdowns as have occurred within the author's knowledge has been arcing between electrodes due to the temporary removal of a portion of the electrolyte by the formation of gas accompanied by an explosion of a large bubble of mixed gas, or of two large adjacent individual bubbles. This seems to be the usual means of striking the arc, although it is conceivable that frothing, due to an insufficient supply of cool electrolyte, might provide means for the overheating of the liquid "conductor" in the case of an alternating-current rheostat, if the voltage gradient across the space between the electrodes were sufficient.

A test to study the modifications introduced by gassing was carried out by means of the small apparatus shown in Fig. 5, in which electrodes 8 inches high and 1 inch wide were confined between glass plates, in order to retain the gas. It was considered that this would represent a section of a much larger plate having

the same depth. The outer faces of the electrodes were thickly stove-enamelled. They were immersed in a 5 per cent solution of common salt, and direct current to the value of 320 amperes, representing 5 760 amperes per square foot, was passed between them. The result was the evolution of large volumes of gas from both electrodes. This gas, however, rose to the surface in fairly small bubbles, and was apparently not capable of causing arcing or other breakdown.

From the above it appears certain that the mere presence of the gas is not sufficient to cause failure at the high current density employed, but that a high temperature, a dirty or stagnant electrolyte, or other additional agency, is necessary to facilitate the evolution of large bubbles, and consequent arcing.

As this test involved the continuous dissipation for some minutes, by a small rheostat having a net capacity of only 8 cubic inches, of nearly 60 kW, the voltage gradient being equal to 2 160 volts per foot, a short

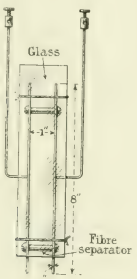


FIG. 5.—Electrodes for direct-current test.

description of the phenomena observed may be of interest.

Violent gassing commenced immediately the current was switched on. A very brisk circulation caused by the rise of heated and gas-laden liquid between the electrodes was set up at once. No particular manifestation occurred as the current density was increased, except the heating of the liquid and the increased evolution of gas, until a current of 256 amperes was registered, implying a density of 4 608 amperes per square foot. At this point explosions began below the surface of the liquid, and were heard as a species of continuous splutter, at the rate of about 8 small reports per second. These explosions were distinctly seen, while the liquid remained clear. On the current being still further increased, flames, and the fumes from them, reached the surface of the liquid, but there was still no sign of any tendency to arc, or of any other interruption. When the temperature of the liquid had reached 160° F., or about 100 degrees F. above that of the atmosphere, the experiment was discontinued on account of overheating in the service cables.

It was observed that soon after what may be called the "explosion point" had been passed, further increases of voltage had a much smaller effect upon the current. For example, 280 amperes passed at 115 volts, 300 amperes at 152 volts, and 320 amperes at 180 volts, in spite of the rapid lowering of the specific resistance of the liquid due to the rise in temperature. For this rheostat, therefore, a limit may be imposed of 4 600 amperes per square foot, beyond which its efficiency and the smoothness of its operation fell off.

Although this apparatus may be to a certain extent discounted as a laboratory appliance, the fact remains that, in dissipating nearly 60 kW continuously over the standard range of temperature without any sign of breakdown, it actually performed the function of a large commercial rheostat, and the results are, at least, striking. Reviewing the various conditions under which this experimental and the practical apparatus work, none can be said to have been extensively modified in the former, with the exception of the very thorough circulation. The conclusion thus appears inevitable, that, given a sufficiently plentiful stream of electrolyte at a temperature well within the specified working limits, current densities up to 4 500 amperes per square foot are practicable, even with direct current. It will be shown later in the paper that at least one type of rheostat complies with these conditions.

Design of Self-cooled Liquid Starters for A.C. Motors of Small and Moderate Sizes.

A usual pattern of liquid starter for induction motors up to about 500 b.h.p. is shown in Figs. 6 and 7. The difference between these is that the former possesses a separate tank and dipper for each phase, while the latter has a single tank, constituting one electrode, the other electrodes being formed by the two dippers, which are individually insulated. Since the function of starting resolves itself into the gradual short-circuiting of the rotor windings, the latter form is sufficient. When using the former for this purpose, either the dippers or the tanks would be connected together, thus joining the liquid resistances in "star." This pattern has, however, the advantage of greater cooling surface and also that it can be used as a "straight through" rheostat, e.g. it can be connected in the stator leads, if desired. As it is intended for starting duty only, no external cooling arrangement is fitted.

This pattern has become the standard for the purpose, and, in general, little exception can be taken to it. Mechanically and electrically it is sound, and it operates without trouble, the only attention required being the making up by the addition of plain water of the loss due to evaporation. Washing soda is generally employed for the electrolyte, and causes little corrosion to the tanks and dippers, which are of plain iron. No means has hitherto been devised for bringing about a complete short-circuit, without the addition of the external contacts. The latter are, however, not particularly troublesome, except that they introduce a slight "jump" at the end of what would otherwise be an entirely smooth acceleration.

The principal point to be settled in connection with the design of this type is its rating. As has already been established, there is practically no limit to the

current density that may be used in the apparatus with impunity, and hence a given rheostat may be used for starting a motor of practically any size, provided that the strength of the electrolyte be adjusted to give a suitable resistance gradient, and that the liquid has sufficient heat capacity to prevent boiling. It is usual to specify that the temperature of the electrolyte must not be raised by more than 100 degrees F. or 56 degrees C. by the operation.

If the rheostat were required to effect a single start only, the horse-power rating, in terms of the motor to be operated, could be definitely fixed, but it is usual, when drawing up specifications for starters, to require that they shall be capable of repeating the operation at definite intervals; for example, the ordinary light-duty and heavy-duty wire-wound starters, not ordinarily to be operated more than twice per hour, must be able

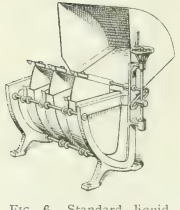


FIG. 6.—Standard liquid rheostat for starting duty up to about 500 b.h.p.

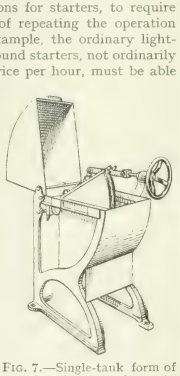


FIG. 7.—Single-tank form of the rheostat shown in Fig. 6.

to start the motor five times in succession (or three times if the resistances are totally enclosed) at intervals of 15 times the starting period, without sustaining any injury. The latter period is specified as 60 seconds for heavy-duty, or a time estimated by the formula $(5 + \frac{1}{2}$ b.h.p.) seconds for light-duty starters; these two classes differing in the relative amount of inertia in the load.

The fulfilment of such a specification for a given motor depends first upon the heat-absorbing capacity of the liquid and iron-work, and secondly upon the rate at which the heat is dissipated into the atmosphere. With regard to the former, the liquid rheostat is in a favourable position as compared with the wire-wound type, on account of the high specific heat and considerable mass of the electrolyte; but the comparison is by no means so favourable as regards cooling, due to the lower maximum temperature and the smaller relative cooling surface of the liquid pattern.

Calculation for Rating (Immediate Duty).

The most convenient unit for measuring the heat-storage capacity of a given rheostat is the horse-power-minute, corresponding to a rise of 100 degrees F.

Now 1 h.p.-minute = 746 × 60 watt-seconds = 10 640 calories.

But the heat required to raise 1 pint of water through 100 degrees F. (or 568 cubic centimetres through 56 degrees C.) = 568 × 56 calories = 31 800 calories.

Therefore to absorb 1 h.p.-minute requires 0·335 pint (10 640/31 800), i.e. practically $\frac{1}{3}$ pint of water. Thus the horse-power-minute rating of any quantity of cold water may be simply found by multiplying by 3 its volume in pints.

In the actual starter, the cast iron of the structure has also a certain heat-storage capacity, which may be allowed for thus:—

The water equivalent of 1 lb. of iron = 0·13 lb.

The equivalent volume of water = (0·13 × 4)/5 pint = 0·104 pint.

Thus a simple way of estimating the water equivalent of the tank, etc., in pints is to divide its weight in pounds by 10.

In an actual case (shown in Fig. 7) the volume of electrolyte is 30 pints, and the tank weighs 70 lb. Thus the total water equivalent is (30 + 7), or 37 pints, and the thermal capacity is 111 h.p.-minutes.

Again, a 10-b.h.p. motor, when started under full load, consumes an average of 5 b.h.p. during the whole period of starting, if the short interval before actual revolution begins be neglected. In this calculation it is assumed that the following starting periods are specified:—

Up to 75 b.h.p.: 1 minute.
From 75 to 200 b.h.p.: $1\frac{1}{2}$ minutes.
From 200 to 600 b.h.p.: 2 minutes.

To start a 75-b.h.p. motor would entail the absorption of approximately 37·5 h.p.-minutes, while for a 200-b.h.p. motor this figure would become 133 h.p.-minutes, and for a 600-b.h.p. motor 600 h.p.-minutes.

The number of consecutive starts that can be made by means of a given liquid starter and a fully-loaded motor, without raising the temperature of the electrolyte by more than 100 degrees F., can now be readily found. For example, in the case of the above starter (Fig. 7), a 222-b.h.p. motor raises the temperature of the liquid by 100 degrees F. in 1 minute. Therefore, a 75-b.h.p. motor raises the temperature by 33·8 degrees F. Thus this particular starter will start a fully-loaded 75-b.h.p. motor three times in quick succession, without appreciably exceeding the temperature specification.

It should be noted that such motors are more usually started at fractional loads, and the rating of the starters can in these cases be correspondingly increased.

The above calculations have been fully verified upon the actual starter and an appropriate motor. They will be found, upon comparison with the rating of the majority of starters in practical use, to permit the carrying out of much heavier work than is the custom at present.

Estimate for Periodic Duty.

Instead of the specification requiring that a number of immediate starts be made, a periodic succession might be stipulated, such as that described for wire-wound rheostats, whereby the starts are separated by

intervals of 15 times their length. In the case of motors up to 75 b.h.p. these intervals would be 15 minutes. Under these conditions the cooling of the rheostat must be taken into account. The effect of such a succession of starts is shown in Fig. 8 for motors of three different capacities, supposed to be fully loaded, the more inclined components of the curves, representing the cooling periods, being copied from the cooling curve in Fig. 9. This is, of course, a logarithmic curve, but

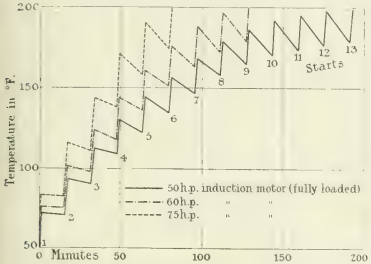


FIG. 8.—Temperature curves resulting from periodic operation of rheostat shown in Fig. 7.

was plotted from the actual rheostat employed (of which particulars have already been given) by filling it with hot water and reading off the actual temperatures at frequent intervals of time. An examination of the ordinates at 10-minute intervals shows that they agree quite closely with the relationship required by the theoretical curve, the ratio between successive ordinates

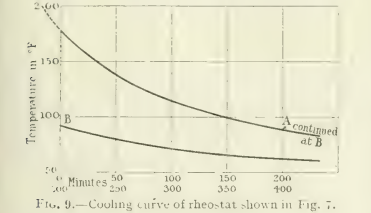


FIG. 9.—Cooling curve of rheostat shown in Fig. 7.

at the interval stated being nearly constant and averaging 0·942.

The nearly vertical components of the curves in Fig. 8 represent the rise in temperature during the starting period, calculated according to the method given in the previous section. The height of these is constant throughout, but the difference in height between the ends of each cooling component depends upon the portion of the original cooling curve from which it is transferred. This is determined by the initial temperature of each cooling period.

In this way the manner in which the starter will heat up after any number of starts can be accurately predicted. For example, after 4 starts under a load of 75 b.h.p. the temperature-rise amounts to 121 degrees F., which is not exceeded until 8 starts have been made at 50 b.h.p. At the former load 6 starts could be just managed without causing ebullition, unless the weather were unusually hot. If the operation were repeated after this point, there would be a certain amount of boiling at the conclusion of each start, but boiling would never occur at 50 h.p. unless the air temperature much exceeded 60° F.

Complete Prediction of Performance.

In the above treatment, a cooling test upon the actual rheostat has been pre-supposed. This would, in practice, necessitate the construction of an experimental model before its capacity could be completely ascertained, and a means for avoiding this is desirable.

Now, it should be possible, with the data already possessed, to supply this missing information by calculation, for the complete curve can be constructed when the ratio between two successive ordinates is known. If this be denoted by K, then $(1 - K)$ is obviously a measure of the rate of cooling, and might be expected to be proportional to the ratio between the cooling surface and the water equivalent of the rheostat.

Expressed in symbols this becomes :—

$$\text{Temperature after } t \text{ minutes} = T_i \times K^{t/10} \quad . \quad . \quad (1)$$

where T_i is the initial temperature, and K is the "cooling coefficient," i.e. the ratio between any two ordinates of the cooling curve spaced 10 minutes apart.

$$\text{Surface ratio} = S$$

$$= \frac{\text{Area of cooling surface in square inches}}{\text{Water equivalent of apparatus in pints}} \quad . \quad (2)$$

where water equivalent = (volume of liquids in pints) + 0·1 (weight of the tank, etc., in lb.)

$$1 - K = \frac{c}{S} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where c is a constant to be determined.

To test the truth of this formula, it has been applied to the two rheostats shown in Figs. 6 and 7. The particulars are as follows :—

	Fig. 6	Fig. 7
Cooling surface	1 271 sq. in.	886 sq. in.
Water equivalent	32·7 pints	37 pints
Surface ratio, S	38·90	23·96
Cooling coefficient, K	0·911	0·942
$\frac{1 - K}{S}$ = c	0·00229	0·00238

The two values for c are sufficiently near together to prove the theory, if it be remembered that the cooling surface of the 3-tank rheostat shown in Fig. 6 is slightly less effective than that of Fig. 7, owing to the fact that the inside faces slightly shield one another.

It will be sufficient for general calculations if an average value be taken for e, when Equation (3) becomes

$$1 - K = 0{\cdot}00234\,S$$

$$= 0{\cdot}00234 \times \text{cooling surface in sq. in.} \div (\text{water in pints}) + 0{\cdot}1\ (\text{wt. of iron in lb.})$$

The above calculation is deduced from first principles and enables the performance to be readily predicted when the dimensions have been fixed according to the ordinary units employed in this country. No separate factor has been inserted to deal with the nature of the cooling surface, as this does not vary to any great extent in practice. The following treatment is more mathematical, and makes provision for a variation in the emissivity.

Consider any small interval of time dt during either heating or cooling. The energy equation is as follows :—

$$P\,dt - TAe\,dt = Ms\,dT \quad . \quad . \quad . \quad (4)$$

where P is the power dissipated,

T is the temperature excess above that of atmosphere,

A is the area of cooling surface,

e is the emissivity,

M is the mass,

s is the specific heat.

When equilibrium has been established and the liquid has therefore reached a final temperature T_m above that of the atmosphere,

$$P = T_m Ae \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Substituting this value of P in (4) we get

$$T_m Ae\,dt - TAe\,dt = Ae\frac{Ms}{Ae}dT,$$

or

$$(T_m - T)dt = \frac{Ms}{Ae}dT \quad . \quad . \quad . \quad . \quad (6)$$

Now $\dfrac{Ms}{Ae} = \dfrac{\text{heat stored}}{\text{rate of radiation}} =$ time-constant of apparatus $= \tau$.

Therefore Equation (6) may be written

$$dt = \tau\frac{dT}{T_m - T}$$

Integrating, we obtain

$$t = -\tau \log (T_m - T) + \tau \log T_m$$

$$\tau \log \left(\frac{T_m}{T_m - T}\right) \quad . \quad . \quad . \quad . \quad (7)$$

When $t = \tau$, $\log \left(\dfrac{T_m}{T_m - T}\right) = 1$

$$T = 0{\cdot}6321\ T_m$$

This is seen to be analogous to Helmholtz's equation for the growth and decay of an electric current in an inductive circuit. In both cases the time-constant is equal to the time required to reach 0·6321 of the final value of the varying quantity, whether temperature or current.

The above equations enable a curve to be drawn either for the heating or cooling of a rheostat.

The direct bearing of the cooling surface upon the rating is almost self-evident. A greater cooling area has been mentioned as one of the advantages of the apparatus shown in Fig. 6 over that shown in Fig. 7. It should, however, be possible to secure the same advantage by corrugating or ribbing the surface of the tank, as is customary with the cylinders of air-cooled internal-combustion engines, and to a less extent with air-cooled transformers. As far as the author is aware, this is not a feature of any existing design; it should, nevertheless, be a definite means of increasing the duty of a given rheostat.

It is important to note that neither of the above calculations holds good if any considerable part of the liquid is exposed to the atmosphere. In the first calculation, equation (2) presupposes that the rheostat is of a type similar to those in Figs. 6 and 7, in which the hinged plate supporting the dippers acts as a complete

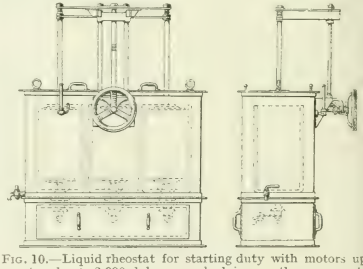


FIG. 10.—Liquid rheostat for starting duty with motors up to about 2 000 b.h.p.; embodying earthenware pots (shown dotted).

cover to the tanks. If this is not the case, and if the surface of the electrolyte is uncovered during cooling, then a cooling curve will need to be plotted, as in the preceding section. Further experiment should, however, be the means of evolving a modification of equation (2) whereby the exposed surface might be taken into account.

LARGER ALTERNATING-CURRENT TYPES.

Two other designs of self-cooled rheostat are shown in Figs. 10 and 11. The former illustrates a type employed in connection with motors of from 600 to 1 700 b.h.p., this particular example being for 800 b.h.p., and having a capacity of 4 450 h.p.-minutes for 100 degrees F. rise. There is a single large tank, with three pots of vitrified earthenware separating the phases. Such pots are very commonly used in these apparatus, but are not always satisfactory. The principal trouble appears to be breakage due to heating applied to the inside only, or to heat expansion against the clamping of a rigid watertight joint. These effects are, however, largely eliminated in the design in

question by immersing the pots completely, so that the hot liquid is in contact with both sides, and by moulding the pots as complete vessels, thus avoiding the need for clamping. Also, in the event of breakage the rheostat is not put out of action by the spilling of the electrolyte. A certain amount of deterioration is caused, in addition, by chemical action on some species of earthenware. For the above reasons, treated wood has been substituted in an American design. The form of electrodes employed, which are of cast iron, do not require auxiliary contacts to complete the short-circuit in the running position.

The second design is adapted for still larger capacities of about 3 000 b.h.p., and differs from those previously shown in having fixed electrodes, the level of the liquid being raised for starting purposes by means of a centrifugal pump. When full speed is reached the operator throws the starting lever into the running position. This action short-circuits the electrodes by means of an oil switch, and stops the pump motor, thus permitting the electrolyte to return to the lower tank. The control handle is so interlocked with the apparatus that it must remain in the starting position until the motor has attained a given speed. No insulating vessels are necessary with this type of rheostat. The acceleration is suitably graded by the use of multiple electrodes of different lengths, the phases being interleaved.

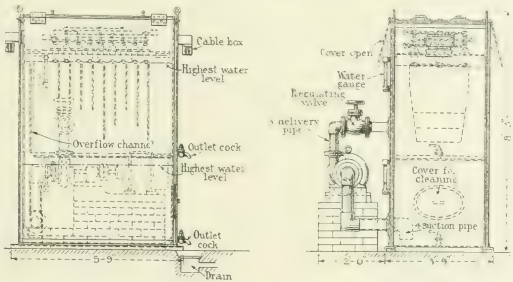


FIG. 11.—Centrifugal-pump type of rheostat, designed for a 3 000-b.h.p. motor.

The Design of Regulators and other Rheostats Requiring Artificial Cooling.

As the size of the motor to be dealt with increases, natural cooling of the starter becomes more difficult, since the heat developed is proportional to the cube of a given dimension, while the surface is only proportional to the square. For regulators and controllers which are required to be in circuit continuously, unaided cooling is almost impossible, except for the smallest capacities, where the "cube-square" law operates more favourably. Some form of circulation is therefore necessary.

If the electrolyte consisted of plain water, it could, where sufficiently pure water is cheap, be simply passed through the tank. Such a design of rheostat, were it attainable in practice, would possess many advantages. For the usual apparatus employing soda electrolyte, however, alternative methods of locating coils of water-pipe in the tank, or of circulating the electrolyte itself through a cooler, are utilized. These two expedients can be applied to the rheostats shown in Figs. 10 and 11, when frequent or continuous operation demands artificial cooling. In the case of the former, cooling pipes can be taken straight through the tank lengthwise above, or on either side of, the cylindrical pots, and connected externally by cast-iron headers; or they may be bent or jointed in such a way as to envelop the set of pots. Iron tubing is generally employed, partly to avoid the possibility of "local battery action" with the solution and the tank or electrodes. In spite of this, however, corrosion is somewhat of a bugbear, and frequently takes place from the inside, being due to the action of the circulating water. If copper pipes were used, this action would not occur, but there would be a risk of electrolytic corrosion of the iron parts. This, however, should be preventible by the use of insulating joints where the tubes penetrate the tank.

Artificial cooling would be applied in the case of the rheostat shown in Fig. 10 by locating cooling pipes in the reservoir below the rheostat tank, thus illustrating the second method. A refinement is introduced into this design when used as a controller, by regulating the height of the electrolyte by means of a weir forming the whole or part of one side of the tank. This weir is raised or lowered by means of the controlling handle, and the pump, which is working continuously in this pattern, preserves the correct time-element by gradually immersing the electrodes up to that height. This form of controller is much used for mine hoists, steel works, and similar work. The control operation in this type is brought to a high pitch of simplicity and certainty.

A description of a rheostat of this general type was given by Rosenberg,* and included a diagram showing the interlocked switching arrangements for reversing

* *Journal I.E.E.*, 1910, vol. 46, p. 431.

service. The principal change within recent years has been the addition of auxiliary shorter electrodes to supplement the three main electrodes. By this means the latter can be spaced further apart and a satisfactory resistance gradient maintained. The great advantage of the wide separation of these plates is that, when the motor is started, the maximum voltage from the line is impressed on the rheostat, while, when it is braked by "plugging," nearly twice this potential is momentarily generated. In both cases the largest plates alone are in the liquid, and the greatest separation therefore exists for the highest voltages. The high potential across the necessarily short spacing in the case of the earlier designs was known to cause trouble. This multiplication of electrodes calls for some little ingenuity in order to maintain the balance between the phases.

The rate of acceleration required is frequently high, full speed having to be reached in 10 or even 7 seconds. In order to fill the rheostat tank (i.e. that containing the electrodes) in that time, a large pump, involving a continuous, relatively high loss, will be necessary. The loss will be reduced, and the apparatus made more convenient and workable, if the tank and electrodes be made smaller. The practicability of employing high current densities, dealt with earlier in this paper, when, as in this case, there is abundant means of getting rid of the heat, should enable economies to be effected in this direction.

This rheostat is a most satisfactory apparatus, its reliability being unimpaired by the presence of large earthenware components in the form of pots. One of its few drawbacks lies in the mechanical force required to raise and lower the weir, and for this reason a small one, preferably rising and falling about a pivot instead of sliding, should be employed.

Liquid Slip-Regulators.

Liquid rheostats for increasing the slip of induction motors have been in use for quite a long time, primarily in connection with the Ilgner system, but it is doubtful whether their performance renders them preferable to a permanently-connected resistance, with its continual heavy waste of energy.

The principal objections to the present design of rheostat are :—

(*a*) *Unreliability*, chiefly through metallic corrosion and the breakage of pots.

(*b*) *Sluggishness of action*, whereby the insertion of the resistance is accomplished too late to obviate current peaks in the induction motor.

The author proposes first to consider briefly the requirements of the dynamic slip-regulator, and the qualities called for in the apparatus, and then to deal with the possible elimination of the defects mentioned under (*a*) and (*b*).

Fig. 12 shows diagrammatically the moving parts of a typical regulator. It is required that the dippers shall be permitted to remain in their lowest position, in which they are short-circuited, until the normal full load of the induction motor has been exceeded. As soon as an overload occurs the torque motor must be able to overcome immediately the mechanical resistance of the system and begin to raise the dippers. If there is any appreciable delay, e.g. the 1 or 1½ second which has been met with in practice, the full peak current, at least in the case of a rolling-mill load with its very rapid acceleration, will come on the line and will merely be curtailed in duration by the operation of the rheostat. Now the avoidance of such peaks is the principal object of the Ilgner system, and thus the apparatus will have failed to justify the expenditure incurred in its installation and maintenance.

The opposition to the movement of the system is due to :

(1) The steady torque to be overcome ;
(2) The inertia of the moving parts ;
(3) Solid friction ; and
(4) Fluid friction.

It is evident that (1) should correspond to full load on the induction motor, in order that slipping shall

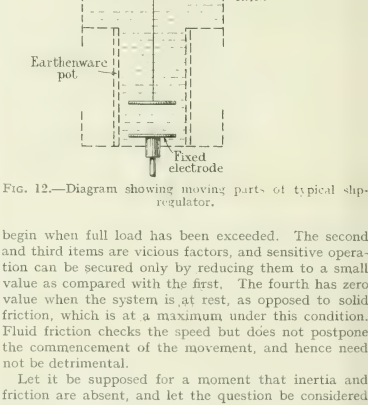


Fig. 12.—Diagram showing moving parts of typical slip-regulator.

begin when full load has been exceeded. The second and third items are vicious factors, and sensitive operation can be secured only by reducing them to a small value as compared with the first. The fourth has zero value when the system is at rest, as opposed to solid friction, which is at a maximum under this condition. Fluid friction checks the speed but does not postpone the commencement of the movement, and hence need not be detrimental.

Let it be supposed for a moment that inertia and friction are absent, and let the question be considered of controlling the movements of the dippers, in order that the travel may correspond to the degree of overload. In this respect the state of things is exactly comparable with that of an indicating meter, and the available methods of supplying the controlling loads are very similar. Of these there are at least four possible alternatives :—

(1) Gravity control by means of a pendulum weight.
(2) Spring control, preferably by the extension of a helical spring or springs.

(3) Solenoid loading.
(4) The weight of the various submerged portions of the rheostat will increase as they rise out of the liquid. This effect might be magnified and taken advantage of.

If such control is omitted, the dippers will tend to rise to the upper limit, thus inserting the maximum resistance, as soon as an overload occurs. The function of the control is to restore equilibrium after movement has begun, and to determine the position of the dippers when each overload occurs.

The above four expedients all have their individual characteristics. Gravity control introduces additional inertia, which would increase the time-lag and make the apparatus more sluggish. Loss of weight upon submergence could be increased by employing tubular supports for the dippers, but is not very promising; while solenoid loading would be complicated and could not fail to add inertia. Therefore, spring control, if any, is indicated. Its effect upon the loading of the induction motor would be that a certain fraction of the overload would be taken by the motor, as an overload is necessary to maintain the deflection of the torque motor.

Another method of enabling the attainment of equilibrium without delaying its inception is by damping the movement of the dippers. This damping is already available in the "dash-pot" effect of nearly disc-shaped dippers moving through the liquid in a direction normal to their faces, and these may be so designed that the damping has the correct value.

The action of the rheostat then would be as follows:—As the normal load is exceeded, the dippers begin to rise against the fluid resistance of the electrolyte, which is a function of the velocity. The induction motor then slips, in consequence of the added resistance, and the current tends to fall to normal as the flywheel gives up its energy. As the current falls, the force exerted by the torque motor also falls, and the movement of the dippers slackens. Normal current in the torque motor will hold the dippers in any position, whereas more current will lift them and less will release them; and this state of things permits the flywheel to take care of the whole of the overload, the peak being practically eliminated from the induction motor.

The designer will have to choose between the two alternatives described above and a combination of both, according to the nature of the problem. For example, it would be fatal to throw all the overload upon the flywheel if the latter were not large enough to supply the whole peak.

With regard to inertia, this will have reached its lowest value if the weight of the dippers corresponds exactly to normal full-load torque, for then no counterweight would be required. This condition is difficult to attain, but it should be approached as nearly as possible. When the rheostat is actually installed the inertia effect can be compensated more or less by adjusting the torque motor to lift at somewhat below the normal full load. This gives a "lead" to the action, but the extent to which it can be used depends upon the uniformity of the cycles of acceleration. It must be remembered that the inertia also delays the reverse action when the load falls, and that the artificial "lead" now becomes a "lag." Many loads, however, such as those in a rolling mill, cease abruptly, and the reverse action of the torque motor then becomes unimportant.

In the author's opinion the usual design suffers through over-complication. It should be remembered that a slip-regulator is a short-circuiting, and not a "straight-through" rheostat, and that there is hence no need for the phases to be insulated from one another. Thus at the outset the porcelain pots would appear unnecessary, and this is important in that much unreliability in the past has been due to their presence. Their insulating effect is neutralized in this design by increasing the conductivity of the electrolyte. To accomplish this, use is made of a stronger electrolyte than would otherwise be necessary, with the result that corrosion problems are accentuated. Thus two mutually conflicting elements are present, each introducing trouble.

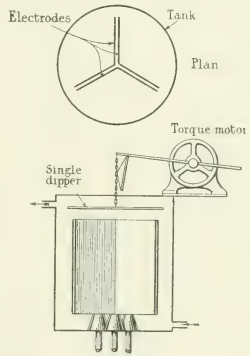


FIG. 13.—Simplified slip-regulator.

The rheostats shown in Figs. 6 and 11 constitute apparatus performing exactly the same functions as the porcelain-pot type, without this complication, and the design of a slip-regulator on simpler lines is therefore possible. Such a rheostat would possess three or more fixed electrodes, which by themselves would interpose the full slip-resistance. A single moving electrode would approach them, and would reduce the resistance to a practical short-circuit. Such an apparatus is indicated more or less diagrammatically in Fig. 13.

A Continental design of slip-regulator does not contain porcelain pots, but is practically an enlarged form of that shown in Fig. 6. In this case the moving electrodes rotate, and the torque motor is geared to the rheostat shaft by means of a chain. This pattern is,

in the author's opinion, designed on more rational principles than that shown in Fig. 12, as it does not incorporate the conflicting and troublesome features described above.

If the simplifications indicated are carried out, inertia and corrosion are reduced and immersed insulators obviated. Thus the principal faults previously enumerated can be lessened, or even practically removed.

Liquid Rheostats for Direct Current.

It will have already been gathered that liquid rheostats are less adapted for controlling d.c. than a.c. apparatus, because of the altered conditions introduced by electrolysis. The disadvantages so introduced are briefly as follows :—

(1) The solution deteriorates; it must be replenished when necessary, and renewed periodically. It is no longer sufficient to make up the loss with plain water as with alternating-current rheostats; but sufficient strong electrolyte must be added from time to time to maintain the conductivity at about its proper value. Fortunately, there is considerable latitude in this respect. When the amount of sediment and scum have become excessive, these must be removed by a complete renewal of the liquid.

(2) Gas is given off, which may, under very exceptional circumstances, become a nuisance.

(3) The anodes are worn away, and require replacement periodically. They are usually designed to do duty for at least 6 months.

(4) There is more chance of breakdown by flashing over when the effects of the electrolysis are present. In addition to the test described on pages 200 and 201, the author has made far-reaching inquiries, and has drawn upon his own fairly extensive experience of this branch of the subject, with a view to the determination of the harmful condition or set of conditions. It is very remarkable how few engineers or operators have ever experienced a breakdown, even with direct current. The test made with the apparatus illustrated in Fig. 5 shows quite effectively that violent gassing, and even explosions and burning of the gases, will not of themselves cause trouble. There is no doubt, from the data that has been collected, that there is no risk of trouble unless the electrolyte is allowed to become very foul, the most pernicious feature being a ferruginous scum that may collect thickly on the surface as a result of prolonged neglect. This has a comparatively high conductivity, and is able to bring about the striking of an arc if the dippers are kept for any length of time in the skimming position.

It will be seen from the above that the only material difference between the use of d.c. and a.c. liquid rheostats is the extra attention needed by the former, chiefly of a cleansing nature. A somewhat more intelligent operator or supervisor is also required for this apparatus. These considerations are not sufficiently serious to be prohibitive; and although the vogue of the d.c. rheostat is at present far less than its a.c. counterpart, its use is increasing as its characteristics become better understood.

There is great scope for development in this apparatus to render it better suited for d.c. working. At present practically the same pattern is employed for both types of current. Improvements should be possible by rendering renewals easy, and by arriving at materials and reactions that would avoid or minimize the deterioration. The latter, for example, is practically absent with copper immersed in a copper-sulphate solution, and an advance along these lines may accomplish the desired end.

Electrolytes.

A knowledge is required of some of the characteristics of the electrolyte to be employed in a liquid rheostat in course of design. The value of the specific resistances of the usual liquids is especially important, as well as their variation with the degree of concentration and with changes of temperature.

Fig. 14 comprises two sets of curves, either of which will give the resistance, at a temperature of 60° F., of the salts that are most likely to be employed in practice. In addition to those mentioned on page 198, sodium bicarbonate and ammonium chloride have been added; while sodium sulphate has also been tested and found to agree sufficiently closely with the carbonate to justify the same curve being employed for both.

These curves give the true resistance with a 50-period current, and this will be sensibly constant for all usual working frequencies. Indeed, a test of the resistance of a solution of common salt, at a density of 240 amperes per square foot and frequencies between 50 and 3½ periods per second, indicated a rise in resistance of between 5 and 6 per cent only, practically all of which occurred between 12 periods and the minimum value.

It should be noted that for these curves the column of liquid had the same sectional area as the electrodes, and that therefore no "fringing" took place.

In the diagram, there are two independent sets of curves, each recording the same set of tests. Those marked "R," which are approximately hyperbolas, give the variation of the resistance of each salt with strength of solution; while those marked "1/R" which pass through the origin and are almost rectilinear, are the reciprocals of the former, and thus indicate the conductivity in mhos per inch cube. There is, however, another interpretation of these curves which renders them of considerable additional utility. The resistance per inch cube is numerically equal to the difference of potential in volts, for 1 ampere per square inch per inch of spacing. The reciprocal curves can therefore represent the spacing in inches per volt at a current density of 1 ampere per square inch. By means of these values, the linear dimensions of the required rheostat can be directly estimated.

It should be explained that the percentages for the strength of the electrolytes have been calculated according to the method that would be most useful in practice, that is, by volume of liquid. For example, a 10 per cent solution could be composed of a gallon of water (weighing 10 lb.), containing 1 lb. of salt.

The variation of resistance with temperature is plotted for three different liquids in Fig. 15. The resultant curves are not far from being coincident; and as the highest and lowest represent the behaviour of

the upper and lower limits of conductivity that would be used in practice, no great error would result from the employment of the middle curve, for all electrolytes. This curve actually records the resistance variation of a 3 per cent solution of washing soda, which is about the most common solution adopted.

An especially interesting example is the so-called "counter cell" employed in connection with the constant-potential method of charging lead batteries. For this purpose it is necessary to maintain a total

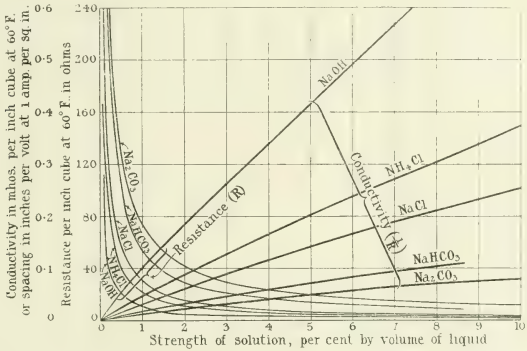

Conductivity in mhos, per inch cube at 60° F. or spacing in inches per volt at 1 amp. per sq. in.
Resistance per inch cube at 60° F. in ohms
Strength of solution, per cent by volume of liquid
NaOH
Resistance (R)
Conductivity (K)
NH4Cl
NaCl
NaHCO3
Na2CO3
KOH

FIG. 14.—Resistances and conductivities of electrolytes at various degrees of concentration.

A further approximation would consist of allowing 1 per cent decrease in resistance for every degree (F.) rise in temperature for the first 40 degrees, and of half this allowance for the next 40 degrees.

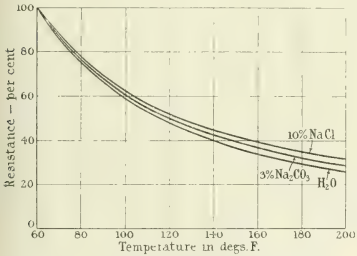


FIG. 15.—Variation of electrolyte resistance with temperature.

The middle curve is very nearly logarithmic, having a ratio of 0·915 between successive ordinates 10 degrees F. apart. This coefficient may also be found useful.

OTHER EXAMPLES OF LIQUID RHEOSTATS.

In addition to the more familiar types, there are one or two examples of the liquid rheostat that are worth describing, in that they present unusual features, or indicate possibilities of extension in its use.

pressure of 2·3 volts per cell. The need for compensation arises when several batteries, comprising an unequal number of cells, have to be charged from the same source. If grid resistances, the standard method for the constant-current system, were employed, the voltage-drop would vary over a wide range as the current decreased and charging progressed. This would seriously violate the condition of constant potential for the operation. Use is therefore made of lead–sulphuric acid–lead units, reference to which has already been made. In these, the lead plates are not "formed" in any way, and the cells simply function as though they were lead batteries perpetually undergoing overcharge. Each one thus interposes a constant negative potential of about 3 volts, and decreases the effective charging voltage by a corresponding amount.

The design of these liquid resistances, as far as spacing and current density are concerned, may be deduced from that of the lead accumulator. The principle underlying their use is one which should render them serviceable in other branches of work.

The following design has been employed by the author for continuous and unattended work in connection with direct-current organ-blowing motors. Its function is to start and then regulate the motor in such a way that the level of the bellows is constant whatever the demand for wind. As will be seen from Fig. 16, its operation is quite automatic, the releasing of a catch being alone required to put the apparatus in full commission.

this rheostat is included herein for two reasons. First, tap water alone is used as the electrolyte, artificial cooling, when required, being brought about by passing automatically a small trickle of water through the tank when the outfit is in use, an expedient which also keeps the electrolyte clean. Secondly, two such apparatus satisfactorily carried out their duties for some years with only the periodical attention usually given to metallic rheostats. The motors were of 1 h.p. and 3 h.p. respectively. In this case, the electrodes were of sheet lead, in the form of a lining to the wooden tank, and a short cylinder respectively. The depth of water was from 4 to 6 inches, and the moving electrode just grazed the surface when the bellows were full, but rested on the bottom of the tank when they were about two-thirds empty. As a result of prolonged use, the lead cylinder, constituting the anode, was eaten away, while spongy lead and litharge were deposited in the tank. Renewal of the anode was therefore needed about every 6 months, while it was of advantage to clean out the tank about every 3 months.

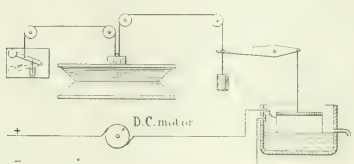


FIG. 16.—Liquid starter-regulator for controlling organ-blowing motor. (Field circuit omitted.)

It is the author's present opinion that this attention would have been much reduced by the use of a cast-iron tank as the anode, with or without a false bottom; and of a cast-iron cylinder as the cathode.

For the purpose fulfilled by this apparatus, the outstanding smoothness of acceleration given by the liquid rheostat was a valuable feature, in addition to the absence of arcing, which, in the usual pattern of organ regulator, is apt to cause trouble at the contacts.

One might be pardoned for considering that electric traction afforded a very unpromising field for the liquid rheostat; yet the latter appears likely to become the standard means for controlling electric locomotives, especially for a.c. working. First used in Italy in 1901, it has been adopted as the standard for all locomotive equipments on the Italian State Railways, and is also employed upon at least one railway system in America. Operation is effected by means of compressed air from the brake reservoir, which forces the liquid upwards, from the lower chamber to the rheostat tank, whereby the fixed electrodes are gradually submerged.

This method lends itself readily to the addition of automatic features, it being easy to control the insertion or removal of the resistance at the desired rate by varying the air pressure. By this means a small "torque motor," similar in principle to that dealt with on pages 206 and 207, is able to maintain an input of constant watts to the main motors. The torque motor is loaded or controlled by a spring in this instance, and the driver is merely required to vary the tension of the spring in order to control the speed of the locomotive.

The capacity of these rheostats is usually between 2 000 and 3 000 h.p. to suit present-day electric locomotives. Carbonate of soda is commonly employed for the electrolyte.*

A torque motor also forms part of a liquid regulator employed for protecting automatic converter substations against overload. The procedure is that as soon as a predetermined load has been exceeded, resistance is inserted into the circuit, reducing the voltage and choking back the current. By this means the apparatus is protected without the supply being cut off.

SPECIFICATIONS.

By employing the results of the tests and calculations described in the preceding sections, it is possible to design a liquid rheostat to give exactly the desired performance, and there is no reason why advantage should not be taken of this to render the apparatus as compact and inexpensive as the data will permit. A few comments are of importance in this connection with regard to the specifications to which the designer may work.

In the past, extravagant standards have been employed. This has been partly due to inexact methods of design, combined with a liberal allowance for contingencies, and partly to the observance of a false analogy which was responsible for the enforcement of rules necessary in the case of wire-wound rheostats but capable of considerable relaxation in the present case.

In the design of a solid resistance, the specification must preclude the possibility that the rupturing point of the resistance material will be passed on a single occasion, for the very sufficient reason that one transgression involves the complete breakdown of the apparatus. With the liquid resistance, on the other hand, the corresponding event is merely the ebullition to a smaller or greater degree, of the liquid, and this is an occurrence that can be contemplated with comparative equanimity on exceptional occasions. In other words, a much smaller factor of safety is appropriate with liquid than with solid resistances, and this is a point of especial importance in the design of self-cooled apparatus.

In the mathematical investigation given in the early portion of this paper it was assumed that a temperature of 100° F. was permissible, this being a common present-day standard. Now the air temperature in this country very seldom exceeds 70° F., and an allowance of 45 degrees F. is thus made over the severest conditions usually experienced, while with the more usual air temperature of about 50° F. to 60° F. the allowance is even greater. In the author's opinion, a specification permitting a working range of 120 degrees F. for certain of the smaller types of rheostats would be justifiable, but, if the present standard of 100° F. is adhered to, the designer would do well to remember that he has in hand a considerable margin of safety to provide against improper use.

* See DOVER: "Electric Traction," pp. 253–6; also *Electrician*, vol. 51, p. 19.

When the quantity of heat to be absorbed is being estimated, it should be remembered also that the starter is only required to dissipate an average of about half the power passing through it during the period of starting. This can be understood when it is realized that, whereas the starter absorbs practically all the energy passing through it when the motor is at rest, yet at the end of the period, when the rotor has reached full speed and the liquid is all but short-circuited, the latter is absorbing practically no energy. As there is an even gradation between these two extremes, it follows that the liquid is heated by only half the horse-power-minutes drawn from the mains. This point has been emphasized, as many starters have been designed in the past on the assumption that they absorbed the whole of the energy at starting.

It is a common practice to require wire rheostats to be capable of effecting an endless succession of periodic starts, and, as was remarked at the commencement of the paper, the high temperature permissible above that of the atmosphere renders this form of resistance inherently suited for rapid cooling. This method of rating is not appropriate for liquid starters, for the reason given. A more suitable requirement would be the carrying out of a given number of successive starts, followed by a sufficient interval to enable the liquid to return to practically its normal temperature. It is impracticable to compile a specification to satisfy all the duties that may be required in practice. A compromise is therefore necessary, and that expressed in the periodic specification was obviously fabricated to fit the solid resistance. It would be as unfair to expect these two dissimilar appliances to comply with exactly the same conditions as it would be to insist that a lead accumulator should conform with the conditions laid down for, say, a Leclanché cell.

No motor for which a liquid starter is used is ordinarily started up every 15 minutes or so throughout the day. If it were required to do so habitually, either an artificially-cooled liquid starter, or one designed for a larger capacity, or a solid pattern of rheostat, should be employed. If the unusual case occurs of a normally-run motor having to start with unusual frequency on an unusually hot day, when it is carrying at every start the full load for which the starter was designed, then, at the worst, nothing more serious can happen than a slight amount of boiling near the conclusion of the later operations.

Conclusion.

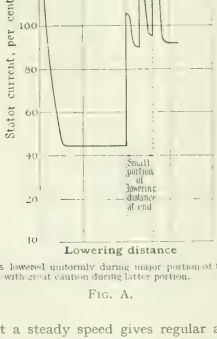
The author has endeavoured to show that the liquid rheostat is readily capable of mathematical design, enabling its performance to be exactly predetermined. It is his contention that advantage should be taken of this fact to fix the dimensions in close correspondence with the desired result, a reasonable margin only being allowed for contingencies. This apparatus has almost a monopoly for the control of the largest motors, and its field is widening for those of more moderate size. There is thus a strong indication that trouble expended in its development will bring in an abundant return.

Discussion before the South Midland Centre, at Birmingham, 23 November, 1921.

Mr. J. Anderson: The liquid starter is theoretically ideal, because the desired accelerating torque can be obtained with the minimum current from the line, but in practice the ideal is far from being realized. Fig. A shows the results recently obtained with a liquid starter on a 550-b.h.p., three-phase 50-period motor driving a centrifugal pump. The peaks are probably due to soda crystals on the dippers causing short-circuits between the electrodes. The tests to determine the permissible current density are very interesting, and the results obtained are revolutionary. Mr. J. H. Rider in his paper * gave 1 ampere per square inch and mentioned trouble by flashing-over on reversal, with the dippers just touching the surface of the electrolyte. These tests assume it to be necessary to have an open position at "off" by withdrawing the dippers, but that seems the worst way to use a liquid starter. Liquid starters should always be interlocked with the circuit breaker to ensure opening circuit on the breaker and closing circuit with the dippers in the right position for the desired initial current. Even interlocking is not a cure, as the level of the liquid may be allowed to fall too low and be only brought to the right level by the attendant after there has been trouble due to open sparking or flashing-over. Has the author any figures for flash-over voltages to confirm those of Mr. Rider? One of the difficulties with a commercial line of starters is that the number of sizes must be comparatively limited. One firm makes four sizes up to 100 h.p.; this range can be covered with two or perhaps three sizes of oil starters, and horse-powers or initial currents intermediate between the maxima are readily obtained by varying the section and resistance of the elements. The case is different with liquid starters, and it is necessary either to stock a range of different sizes of dippers or to vary the density of the solution, or both. Dippers and solution require changing from time to time, and there can be no guarantee that they are not altered on site and the starter overloaded, or the motor unduly stressed. The author cites tests to show that there is little corrosion with 25-period supply. This does not agree with a test made some two or three years ago. A resistance element consisting of a porcelain cylinder wound with alloy resistance wire about No. 20 gauge was immersed in Birmingham tap water, and after a 25-period current had been applied for 2 hours the wire had rotted through and broken the circuit; I believe that the potential between the ends of the cylinders was 100 volts. The corrosion with direct current is generally heavy, and the average life of cast-iron electrodes in haulages is not more than 6 months, so that a starter in frequent use must have ample facilities provided for changing the electrodes and the solution, and clearing out sludge.

* "The Power Supply of the Central Mining Rand Mines Group," *Journal I.E.E.*, 1915, vol. 53, p. 609.

Total enclosure to meet the Home Office Regulations as to the Use of Electricity in Mines is not easy with small horse-powers. The decrease of resistance with temperature must be troublesome and fatal to exact work. The temperature coefficient in Fig. 2 is between 0·0065 and 0·008; taking the average as 0·0072 at 100 degrees F. rise, the resistance will be 28 per cent of the initial, i.e. the initial starting current will vary in the ratio of 1 to 4 from cold to hot. A soda solution does not freeze easily, but the possibility must be taken into account if the starter is in an exposed position. The author refers on page 201 to the current-rush on short-circuiting the dipper type of rheostat; this rush may be sufficient to open the circuit breaker if the starter is not correctly proportioned. The experimental pattern shown in Fig. 3 is theoretically the correct type, because lowering the



Note.—Plates lowered uniformly during major portion of travel, and much more slowly and with great caution during latter portion.

FIG. A.

electrode at a steady speed gives regular acceleration, and at the end of the travel the resistance is zero. The dipper type which includes the type with rising liquid (see Fig. 11) is fundamentally wrong, because the dippers have to be lowered at an increasing speed to obtain regular acceleration unless the plates are of a parabolic form to obtain a rapidly increasing area per inch of immersion. It is for this reason that multiple plates are used in the type shown in Fig. 11. There is a certain final minimum resistance when the dippers are at the bottom or the liquid is at the highest level, and if this is equal to the motor resistance in the case of series motors, or to that of the armature in the case of shunt motors, the current-rush will reach 200 per cent and trip the circuit breaker. The method described on page 202 is standard, but only the first few peaks and valleys and the last are of much utility. The last peak and valley simply indicate that the number of watts put into the starter during the accelerating period must equal the watts which the starter can dissipate during the cooling period when working on a cycle. This method is not quite so easy to apply in practice as it appears, and it is a far cry from the general statement to the works data; in the case of a liquid starter, allowance must be made progressively for the decreased specific resistance of the solution, the actual decreased resistance and increased weights of electrolyte and cooling surface. In the case of air-cooled and oil-immersed starters many corrections have to be introduced, and the case of shunt and series solenoids offers scope for much calculation, because in the former the watts decrease with temperature-rise, and increase in the latter. On page 203 it is assumed that the measured areas of cooling surface are equally effective; this is far from being the case and it is sometimes very difficult to estimate what is the true effective cooling surface. Tests to determine the efficiency and correct proportions for cooling ribs are very perplexing in their results. If the rib is solid there are definite correct proportions for the width of the base and the depth and spacing apart, both vertically and horizontally; generally the effect is disappointing and out of proportion to the cost on starters. A glance at any large transformer will confirm this, if it be remembered that the transformer tank has to dissipate only about 2 per cent of the rated horse-power, while a starter has to dissipate 30 to 50 per cent of the motor horse-power. On page 206 the author refers to forced cooling, but at the temperature-rises permissible this is costly and is analogous to cooling the circulating water of a steam engine surface condenser. On page 210 the author refers to the iniquities of standard specifications, and rightly so. As regards temperature-rise why should not the liquid be permitted to boil, and steam be generated under pressure at temperatures between 300° F. and 400° F.? It is a serious waste of material to try to dissipate energy at 100 degrees F. rise, and to throw away the possibility of utilizing the latent heat of steam in short-rated starters. On page 211 the author mentions a sufficient interval to enable the liquid to return to practically its normal temperature, but Fig. A shows this is to be a matter of nearly $3\frac{1}{2}$ hours for a range of about 85 degrees F.

Mr. H. C. Fox: The facility with which the resistance can be varied by modifying the strength of the electrolyte is mentioned as being a valuable feature. Is it not rather a weak point, as the user, who possibly knows little or nothing of the matter, is left to supply the resistive element, which would not be agreed to in the case of metallic rheostats? The harmful effect of ebullition do not entirely disappear on cooling. Evaporation will have taken place, reducing the quantity of electrolyte and increasing its strength, and this may reach a serious stage before receiving attention. Tests do not in my opinion establish that with alternating current of any periodicity electrolytic action is negligible. The point is of importance when the rheostat is in series with the rotor circuit of a lightly loaded induction motor. Here the frequency is of the order of 1 or 2 periods per second unless the

resistance is very high, and in such circumstances I think a certain amount of electrolytic action might be anticipated as direct-current conditions are approached. The troublesome jump on final short-circuiting might be considerably reduced by making tanks of the sections shown in Fig. B. This method should dispense with the parabolic blade-form mentioned by the previous speaker. The author has assumed that the average horse-power dissipated during starting is 50 per cent of the continuous horse-power which would be given out by the motor when taking a current equal to that passed during the starting period. Since the resistance/time curve must be a parabola if the current is to remain constant during starting, it follows that the horse-power to be dissipated must be 66 per cent. This, of course, means that the starter for a given motor would have to be 33 per cent larger than the author's figures would give. Stator resistance starters to realize 100 per cent starting torque are inadvisable, on account of the exceedingly heavy starting current required. Not only is the current heavy at the moment of starting, but it maintains a high percentage of its initial value during the major part of the starting period. Even with 30 per cent

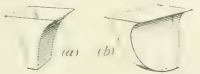


FIG. B.—Design of tanks to reduce the jump on short-circuiting.

a, for plates lowered vertically.
b, for plates lowered radially.

starting torque, the starting current is of the order of 250 to 300 per cent of normal full load, and a starter much larger than a rotor starter for similar starting conditions is necessary for such starting conditions. The increased rating obtained by ribbing the tank would not be worth while. A prominent designer of internal-combustion car and cycle engines has shown that the ribbing of cylinders of air-cooled engines has much less effect than is commonly supposed, and for this reason his latest designs bring all but the combustion head inside the crank case, the cooling being effected by circulation of oil. If the whole tank is to be filled with electrolyte, why are pots used in the type shown in Fig. 10?

Mr. C. Sutton: I should like to ask the author what maximum temperature he would suggest as a standard for self-cooled rheostats. It may be of interest to give particulars of a special type of liquid rheostat, primarily designed for use in connection with ship-propulsion motors. Twelve of these rheostats were made, each to be capable of absorbing 100 h.p. continuously. Figs. C and D give cross-sections in elevation and plan of the rheostat, which is of the artificially-cooled stationary-electrode type. The figures are more or less of a diagrammatic form. In the central portion of the rheostat is a vertical cooler D. The bottom header of this cooler is divided at the centre by a vertical plate, the cooling water being passed into one side of this header, from which it flows up half the cooling pipes into the top header, flowing back down the other pipes and thus out of the apparatus. The path of the cooling water is shown in Fig. C. The electrolyte is pumped into the cooler through the pipe K, and overflows at the top of the cooler into the surrounding narrow annular space F. At the bottom of this space there are three openings (J) 120° apart, through which the electrolyte passes into the electrode chambers. These chambers are formed by an annular space divided into three separate compartments by three special cylindrical weirs spaced 120° apart. The weirs consist of inner and outer cylinders A and B, the inner cylinder being so arranged that it can be revolved through a small

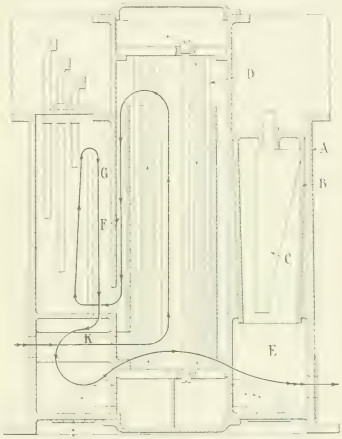


FIG. C.

angle. V notches C are cut in both cylinders having the electrode chambers, in such a position that the height of the electrolyte in the electrode chambers can be varied by revolving the inner cylinder. The electrolyte overflowing the weirs falls into the sump (E) formed in the base of the main tank, and from this sump is returned to the pump thus completing the circuit. Additional overflows (G) are arranged in each chamber. The path of the electrolyte as shown in Fig. C is correct when the weirs are closed. If the weirs are opened, however, the electrolyte does not reach the overflows and falls into the sump through the V notches in the weirs. The electrodes are of nickel strip bent into tubular form, with an outside diameter of $\frac{3}{4}$ inch. These tubes are brought into the electrode chambers through porcelain insulators and

are carried at the top by copper sectors to which the tubes are bolted. The electrodes are of different lengths, and so arranged that when the electrolyte first makes contact with the electrodes there are very few in circuit and these are at the maximum distance apart. As the level of the electrolyte rises, more electrodes which are nearer together come into circuit, until finally all the electrodes are immersed, giving maximum surface and minimum distance. A concentric cylindrical arrangement has been adopted for the electrodes, the phases in the different chambers being cross-connected in order to obtain an exact balance of resistance under all conditions. It was found on test that by varying the lengths and position of the electrodes practically any shape of resistance curve could be obtained. We have not been able to test these rheostats up to their limit, but from tests we have made it was evident that this limit was much

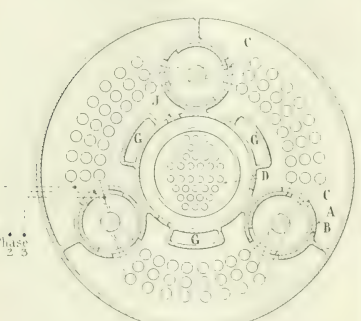


Fig. D.

higher than we expected. The maximum current density reached during tests was 3 200 amperes per square foot. A set of iron electrodes was tried in one of the rheostats and proved quite satisfactory. The author's principal criticisms of the stationary-electrode type of rheostat seem to be: (1) A large pump is required to fill the electrode tanks quickly when a high rate of acceleration is required; and (2) the mechanical force required to operate the weirs. In the tests which we made, two resistances were coupled together, one pump supplying the electrolyte for both, and one hand-wheel operating all the weirs. The pump took 2 h.p. and filled the electrode chambers in less than 10 seconds. This is less than 1 per cent of the continuous capacity of the rheostat. The hand-wheel operating the weirs was also coupled to a shunt regulator on the switchboard, and no appreciable power was required to turn it. The advantages of this design of liquid rheostat seem to be: (1) Compactness; (2) ease of working and small moving parts; (3) flexibility—the shape of the resistance curve can be varied over a wide range; (4) ease of renewals—any electrode can be replaced in a few seconds; (5) efficient cooling—all the electrolyte comes into direct contact with the cooling pipes at a high speed; (6) the cooling pipes are straight and can be withdrawn very easily; and (7) the apparatus is totally enclosed, with the exception of a vent pipe. The frequency of supply across the rheostat was varied between 20 and 60 periods per second without any measurable difference in resistance.

Mr. B. A. M. Boyce: The company with which I am connected has supplied to one client 262 of these starters during the last 7 years, and during this time the spare parts ordered have been only 4 sets of contacts and 9 sets of dippers, thus showing the soundness of their construction. With regard to current density on the electrodes, it should be borne in mind that the density with full immersion given in pocket-books will most likely be exceeded considerably when the electrodes are only partially immersed. I should like to ask the author if he has had any difficulty with high voltage between electrodes just before they are short-circuited. In one case which came to my notice a large rheostat, working on the double-cone principle with the electrolyte flowing up between the cones, gave a minimum drop of 54 volts with the cones less than $\frac{1}{8}$ inch apart. The effect of short-circuiting at this voltage was to burn up the contacts and open the main induction-motor circuit-breakers. The motor was rated at 800 h.p. The cones were of nickel; with cast-iron cones the voltage was higher. A small model did not give this effect. With regard to frequency, I think there is a critical frequency between 25 and 40 periods per second, and that below this critical point the effects of alternating and direct current are similar.

Professor W. Cramp: In addition to the figures given in the paper the author has shown a slide connecting the resistance of one electrolyte with the distance between the electrodes. I hope that he will include this in the *Journal* as it is of great use and I do not think that it has been published elsewhere. The deductions which he makes from his experiments will be rendered much clearer if he will add for each experiment the analysis of the electrolyte. In connection with Fig. 2 he refers to the use of "plain water." This is a very vague term, as water in different localities varies widely in its behaviour as an electrolyte. Again, I do not agree that Fig. 4 proves the absence of the "surface effect," but merely that in alternating-current circuits the surface effects neutralize one another. It will be noted in connection with this remark that the line in Fig. 4 does not pass through zero, as it undoubtedly should do if all surface effects were absent. We do not know what is the effect of the proximity to the electrodes in Fig. 3 of the surface of the containing vessel. Throughout the paper the basis for the calculation of the surface densities is unsatisfactory, for the fact that there is insulation at the backs of the plates does not mean that there will be no current therefrom. A damp surface is a good conductor, and it is almost certain that the potential of the back of the plate and the rod in Fig. 1 would be nearly the same as that of the face of the plate. If this be the case the

current densities are materially changed, especially as regards their distribution between the plates. In the calculation for rating, the author omits very important factors, viz. the effect of the thickness of the vessel, and the consequent temperature-fall therein, and the effect of evaporation from the surface of the liquid. The latter may be quite large. In his prediction of performance he does not say how he calculates the area of the cooling surface, and I should like him to say exactly what he includes under this head. It seems to me to be a great pity that two methods of calculation should be given without any connection between the symbols of the two being shown, although the basis is the same in both cases. As a matter of fact, the value $(1-K)$ in the first method is proportional to Ae/Ms in the second. The value of the paper would be enhanced if the author would show this connection clearly. In any case I must protest against the form of the equation at the top of page 204. The confusion of units alone in this equation is enough to condemn it. I cannot agree that the method of deriving the constant c warrants the author in regarding it as a constant, or in giving its value to 5 decimal places. Much more evidence is needed on this point. Whichever series of equations is adopted the author will agree that everything depends on the correct estimate of the time-constant of the apparatus. Now, the experimental method put forward by the author may be checked in the following way :—Differentiate equation (7) with respect to time, and put $t = 0$, when we find $dT/dt = T_m/\tau$. Also $T_m = P/Ae$, so that $\tau = P \tan \alpha / Ae$, where α is the angle which the temperature/time curve makes with the temperature axis near the origin—easily obtained experimentally to a fair degree of accuracy. In conclusion I should like to assure the author that I think the paper especially valuable as demolishing the old conventions regarding limiting current densities.

Mr. A. E. Angold : I should like to ask the author whether he has found any difference between the results obtained with electrodes arranged in vertical planes, and those arranged in horizontal planes. I suggest that with horizontal electrodes the products could not escape so easily, and therefore would not carry as high a load as the vertical electrodes.

Mr. T. Simmons (*communicated*) : At collieries liquid rheostats are mostly used to start up motors driving large endless haulage gears, where the intervals between the starting of the motor are rather long. I do not consider liquid rheostats very adaptable for controlling motors driving main and tail drum haulages where the stops and starts are very frequent. I have in mind a small 30-h.p. haulage set working underground. The interval between two hauls would be not more than 4 to 5 minutes and the motor would have to start up with full-load torque. Under these conditions the electrolyte would evaporate rather quickly and one could not depend upon a motor attendant to fill the container with electrolyte of the correct strength, and this is where the trouble would commence. The use of liquid rheostats would be impossible where Rule 132 of the Home Office Regulations as to the Use of Electricity in Mines is in force. When the electrode makes or breaks contact with the electrolyte a spark is always present. Is there any reason why the electrodes should leave the electrolyte ? Some wire-wound rotor starters are designed so that the motor starts up when the line switch is closed. This design also might be applied to liquid starters. To stop the motor it is necessary only to open the line switch, but provision would have to be made to interlock the main switch with the starter, so that the line switch could not be closed with the starter in the "full on" position.

Mr. W. Wilson (*in reply*) : I thank Prof. Cramp and other speakers very much for their kind remarks by way of endorsing a number of the points I have endeavoured to make in the paper. In response to Prof. Cramp's first request, I have added the resistance curves, somewhat amplified, to the paper, where they appear as Fig. 14. The identities of the electrolytes and frequencies used for the tests were made somewhat obscure in one or two places in the original draft owing to the interpolation of fresh matter in a description of a continuous test, and this has been rectified in the final revision.

The few instances of unsatisfactory performance that occur to-day are practically all the results of neglect or misuse that no electrical apparatus can be expected to withstand, even one so robust as that in question. Where dirt is permitted to collect on conducting surfaces, worse results than those shown in Fig. A are experienced, even with metallic starters, and crystals should certainly be classed as "dirt" in this connection, as they have no business on or in any part of a liquid rheostat. With regard to "flashing over," I have never known or heard of this or any other similar breakdown occurring to a liquid resistance, which was not exposed to a combination of three special conditions. These are: (1) a boiling electrolyte, (2) a prolonged "skimming" position of the electrodes, and (3) either a voltage gradient exceeding 680 volts per inch of spacing, or else a very dirty electrolyte, with a conducting metallic scum floating on the surface. To keep the dippers just touching the surface is comparable with holding a knife switch with the blade touching one corner only of the jaws; the operator who does either is asking for trouble, though it is true he seldom gets it with the former apparatus. The case described by Mr. Rider, on page 616 of his paper,* is that of an old pattern of liquid rheostat installed about 11 years ago, in which a voltage of 1 500 was applied, upon the reversal of the motor, to plates only $\frac{3}{4}$ inch apart, while they were skimming the surface. I have already referred (see page 210) to this problem and the way in which it has been solved. I have no figures other than those quoted by Mr. Rider for flash-over values; but I should regard the test he described on the same page as authoritative, and satisfactory as indicating by its stringency the peculiar robustness of the liquid rheostat. For current density, the same author was able to state then that "a density not exceeding 1 ampere per square inch has been found to be a safe limit"; but I think it will be agreed that the present paper has considerably extended this limit.

* "The Power Supply of the Central Mining Rand Mines Group," *Journal I.E.E.*, 1915, vol. 53.

Contrary to Mr. Anderson's supposition, fewer sizes of liquid starter are required to cover a given range than is the case with metallic starters, as will be evident if any catalogue listing both types be consulted.

The water-cooled resistance test does not appear to have much bearing on the subject. It is well known that the immersion of a metallic resistance in water has no very appreciable effect upon the resistance, and therefore no considerable fraction of the current can pass through the water. Thus, much electrolysis can in no case occur whatever the frequency or type of current. I am unable to advance a reason for the "rotting" effect, as a repetition of the test by myself, as closely as Mr. Anderson's details would permit, failed to produce even superficial tarnish, although it was continued during the whole of a working day. In the same speaker's estimation of the temperature coefficient of the electrolyte used in Fig. 2, I am inclined to think the percentages have been based in each case upon the lower of each pair of temperatures, instead of upon the original temperature from which heating began. The true coefficient, as calculated from the full-line curve, varies from 0·0055 to 0·0061, giving an average value of 0·0058, instead of 0·0072. Thus the resistance at 100 degrees F. rise is not 28 but 42 per cent of that when cold, implying a variation of only 1 to 2·4, instead of 1 to 4. The figures obtained from Fig. 2 will be seen to agree quite closely with the resistance/temperature curve in Fig. 15, which has been added to the paper since the first reading. Even this reduced variation might well be a serious matter in a metallic rheostat, where the resistance is finite and the number of steps limited; but it is of very small importance in a liquid apparatus, where the speed of operation of the starting handle can be varied with impunity in accordance with the acceleration of the motor, thereby securing the desired resistance gradient. The tapering variation of resistance with dipper rheostats mentioned by Mr. Anderson need not occur except with the smallest types, since for all but these the electrodes are double, and approach the sides of the tank as they descend. This design affords great control over the resistance curve, and renders parabolic dippers or tanks alike unnecessary. It also deals quite effectively with the magnitude of the "residual" resistance.

The method for estimating the temperature-rise given on page 203 has been perfectly simple to apply in practice, and was designed with that special object in view. No corrections whatever are necessary in using it. It has not been assumed that all portions of the cooling surface are equally effective. The only assumption involved is that with rheostats of different sizes but of approximately the same form, corresponding portions of the surfaces possess similar cooling values in each case. The transformer analogy does not appear to illuminate the question of rib-cooling very much. The speaker's argument appears to be that if the ribs were much good they would radiate not only the 2 per cent of the input that is converted into heat, but also some of the 98 per cent that is delivered as electromagnetic energy. I am glad that Mr. Anderson has expressed himself as being in favour of allowing rheostats to boil. If specially designed for this condition they would be quite sound, and should be capable of t adaptation that the speaker proposes. Ordina patterns, especially the smaller sizes, may cau fluctuation of the resistance and current if ebulliti sets in.

Mr. Fox claims it as a drawback that the user m control the value of the resistive element, which cannot do in the metallic rheostat. Since even in t latter case he can control the amount of the load the motor and the speed with which he moves t starter handle, both of which affect the starting p formance far more vitally than the specific resistan of a step-less rheostat, the "drawback" is a small o These two considerations by themselves show that is futile to attempt an extreme degree of exactitude starter design, unless the speed of operation is clos governed by automatic means and the motor load taken into account.

Mr. Fox's resistance/time calculation does not see to be quite correct. I imagine the reference is to t resistance/(number of steps) curve employed for t design of the solid starter in order to keep the curren maxima constant, and thus limit the number of ste for a given peak current to a practicable value. Th curve, however, is not parabolic, but logarithmic. the current value did vary according to this or a simil curve, the power absorbed by the starter would approximately 33 per cent less, and not more, th I have stated. As a matter of fact the resistance/tim curve for constant current is a straight line, as M Anderson has indicated in his comments upon Fig. In Fig. 10, the pots are used to isolate the electroly through which the upper electrode of each phase h to move. Otherwise it is evident that the curre would simply pass from one lower electrode to the oth and the moving element would produce only a sma effect.

I was particularly interested in the rheostat describ by Mr. Sutton and shown in Figs. C and D. It is design that is based upon sound principles, and t novel features involved all appear to be justified, wi possibly the sole exception of the nickel electrod which the speaker himself has intimated may replaced by iron without causing trouble. The su cessful use of a current density as high as 3 200 amper per square foot is a much appreciated confirmati of my own contention. In response to his inqui regarding a standard maximum temperature for se cooled rheostats, it is evident that up to boiling poi no change has been effected in the conditions exce the variation of the specific resistance, which I ha endeavoured to show is unimportant when the latt is not divided up into steps. The requisite allowan to provide against contingencies is rather a debatab point; but in view of the small damage that wou result upon transgression, my own opinion is th 20 degrees F. would be ample. This brings the standa temperature limit down to 192° F., which I consid to be satisfactory.

The particulars afforded by Mr. Boyce as to t almost negligible replacement of electrodes required 7 years are also of great interest. This informati may be expressed numerically as an annual renew

of 0·22 per cent of fixed, and 0·49 per cent of movable electrodes, up to the seventh year of the life of the apparatus. Hitherto I have met with no trouble due to high voltage prior to short-circuiting, and I have found that perfectly flat electrodes gave quite satisfactory results in a cylindrical pattern of rheostat similar to Fig. 10, unless of course the electrolyte was much too weak. With regard to the existence of a critical frequency, some of my tests were taken down to $3\frac{1}{2}$ periods per second, and although there was a slight accession of electrolysis as this point was reached, the curve was a perfectly gradual one for the sodium chloride solution employed, without any suspicion of a knee. On the other hand, quite brisk evolution of oxygen and hydrogen occurred with a 3·5 per cent solution of sodium bicarbonate at 30 periods per second, 66° F. and 1 152 amperes per square foot, the potential difference being 26 volts across $\frac{1}{8}$ inch. Although for every electrolyte there must be a periodicity where electrolysis ceases to be negligible, my own experience goes to prove that this value is not clearly defined, that it varies for different liquids, and that it may be ignored for practical purposes with the usual electrolytes.

Prof. Cramp has made a number of valuable comments, some of which have already been referred to. The "plain" water referred to at the top of page 199 was Witton tap water. I hardly think the resistance of a sub-aqueous damp surface is likely to affect the calculations to any practical extent. If the voltage at the back of the plate had been as the speaker conjectures, gas would have been evolved there in the experiment relating to Fig. 5, which was not the case. That the curve in Fig. 4 passes the vertical co-ordinate above the origin means in this case that when the electrodes were touching, and therefore when the "surface effect" did not enter into the case, there was still some resistance between the voltmeter leads. As far as I can remember, the meters were located upon the instrument panel of the testing equipment, in which case this part of the current-carrying connections might well have an appreciable resistance. If the curve had passed through the origin and had immediately afterwards moved up to its present course, then an appreciable surface effect would have been indicated.

The first calculation for rating is intended for the use of factory designers, and the formulæ that have been evolved are therefore expressed in the standard English units employed in manufacture. Prof. Cramp will remember that the constant "c" is derived from an actual temperature test upon two of the rheostats. The thickness of the vessel is therefore taken into account in this value, provided that the thickness varies approximately with the other dimensions. The latter is so usually the case that the author did not consider the complication to be worth introducing. I quite agree that evaporation from the surface would cause a big discrepancy; in fact a number of tests carried out upon open tanks indicated that this condition was very hard to provide for. The formulæ on page 204, as they stand, are only intended to do duty for such apparatus as those in Figs. 6 and 7, in which the surface of the electrolyte is completely covered by the descending dipper-support. The latter is included in the calculated cooling surface. A proviso to the above effect has been inserted in the text to make this clear. The constant is certainly given to five places of decimals; but as it may be written $2{\cdot}34 \times 10^{-3}$, it will be seen to possess only three significant digits, and is therefore not over-exact. I am indebted to Prof. Cramp for the interesting method of checking the experimental results by the second calculation. The expression may, however, be obtained directly from the second form of equation (6) without differentiating back from equation (7). For equation (6) may be written:—

$$\frac{dT}{dt} = \frac{T_m}{\tau} - \frac{T}{\tau}$$

the last term vanishing when $T = 0$, i.e. at the origin.

In reply to Mr. Angold, the apparatus in Fig. 1 was also arranged to work with the electrodes vertical, and the test described above was carried out up to a certain point with this modification. Exactly similar results were secured; but if the current densities had been increased to the "steam point," I am convinced that Mr. Angold's statement would have been fully borne out.

The loss from evaporation in the case of Mr. Simmons's rheostat would be made up with water, not electrolyte of some carefully fixed strength. This entirely alters the case, and the liquid controller is therefore quite in order for the purpose named. None of the rheostats shown in the paper would be entirely safe in a gassy mine. Total enclosure is in the author's opinion the only safeguard, by means of an envelope sufficiently strong to resist internal explosions, and having sufficiently wide flanges at all joints to cool the products of combustion to a safe temperature. These requirements are almost prohibitive. The suggested interlock is always employed with large motors.

THE EFFECT OF HEAT ON THE ELECTRIC STRENGTH OF SOME COMMERCIAL INSULATING MATERIALS.*

By W. S. Flight, Associate Member.

Paper first received 1st October, and in final form 15th November, 1921.)

Summary.

Of the three principal constituents of electrical machinery the greatest improvements in the future are to be looked for in the insulating materials. A knowledge of the effect of heat upon the electrical and mechanical characteristics of insulating materials is of the greatest practical importance. An investigation has been carried out to ascertain the variation in electric strength between temperatures of 30° C. and 100° C. of many of the solid insulating materials at present employed in the manufacture of electrical machinery and apparatus. These tests show that in the case of some of the materials used at present the breakdown voltage at 100° C. may be only one-half that at 30° C. Except in the case of certain mica products the electric strength of all the materials was found to decrease appreciably with increase in temperature. Consequently, all insulating materials should be judged and used in accordance with the breakdown voltage at 100° C. and not on the results of tests carried out at air temperature. Further research work would appear desirable: (*a*) to investigate other materials on the lines of these tests, and also the effect of heat on the mechanical properties; and (*b*) to develop new insulating materials with better electrical and mechanical properties at temperatures likely to be attained in modern electrical machinery.

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(1) Introduction.

In the early days of the electrical industry when comparatively little was known of the properties of the materials used, designers of electrical machinery were naturally very liberal in the quantity of iron, copper and insulation which they employed in electrical machinery and apparatus. Before long, however, serious commercial competition developed and more knowledge was acquired of the behaviour of the materials under different conditions of service. This resulted in the weight of material per kilowatt of rating being steadily reduced, until at the present time the controlling factor in many designs is the temperature which the insulating materials will withstand. Of the three principal constituents of electrical machinery, there does not appear to be much hope of further improvement in either the iron or the copper, but the insulating materials are undoubtedly capable of considerable further development, and it is chiefly to the insulating materials that we shall have to look for future improvements in electrical machinery. As so little has been published relating to the effect of heat on the electric strength † of the commercial insulating materials, it is hoped that the following results of some tests carried out in this connection will be of interest and service to both designers and users of electrical machinery and apparatus.

(2) Other Factors Influencing the Electric Strength.

The electric strength of a solid insulating material is influenced not only by the temperature of the material but also by a number of other variables, all of which have to be taken into account before an investigation of the effect of temperature can be made.

The following are the most important factors to be considered to enable the test conditions to be standardized so that the effect of variation of temperature can be studied :—

(*a*) *Test equipment.*—The high-tension transformer should have an output of at least 5 kVA and should be excited by an independent alternator with an output of at least 10 kVA. The applied frequency should be about 50 periods per second, the wave-form as nearly sinusoidal as possible, and the voltage capable of being raised without breaking the circuit, by means of a rheostat in series with the field of the alternator. The testing set employed for the majority of the tests quoted in this paper complied with the above conditions except that the alternator was smaller than desirable for the testing transformer used. From oscillograph records it was found, however, that this did not cause any serious distortion of the wave-form for the tests conditions prevailing during the investigations.

* The Papers Committee invite written communications (with a view to publication in the *Journal* if approved by the Committee) on papers published in the *Journal* without being read at a meeting. Communications should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† By "electric strength" is implied the voltage required to break down unit thickness of the material. For thin materials, such as paper, this is usually expressed in volts per mil or volts per mm. For thicker materials, such as porcelain, it is usually expressed in kilovolts per cm. Throughout this paper the electric strength is expressed as volts per mil.

(*b*) *Thickness of insulation.*—It is known that the electric strength decreases as the thickness of the dielectric is increased. As the insulating materials under investigation were used over a range of thickness, the effect of temperature on different thicknesses was studied. To permit of a comparison being made between one class of material and another, curves showing the variation of electric strength with thickness at various temperatures were obtained, and from these the breakdown voltage of a thickness of $\frac{1}{16}$ inch of the material was calculated. In the case of some of the materials it was found possible to obtain direct results on a thickness of $\frac{1}{16}$ inch.

(*c*) *Shape of the insulating material.*—As all these tests were carried out on flat sheets or on cylinders of large diameter (not less than 8 inches), and as a standard shape of electrode was employed throughout the tests, the distribution of dielectric flux was considered to be the same in all similar tests on the different materials.

(*d*) *Duration of application of voltage.*—The electric strength decreases to a certain minimum value as the time of application of the voltage is increased. If a lower voltage than that which gives the lowest electric strength is applied to the insulation, the latter will not break down even after an extended application. The British Standardization Rules specify that the high-voltage test on finished machines shall be applied for 1 minute, and test-results which are applicable to a 1-minute test are of more value than those which have been obtained by raising the voltage more rapidly. To step up at intervals of 1 minute from zero to breakdown would in most cases take far too long and, as the duration of application of the lower pressures has practically no influence on the breakdown voltage, it was decided first to apply for 1 minute a voltage about 5 kV lower than the expected breakdown voltage. At the commencement of a series of tests some idea of this latter voltage was obtained by applying the pressure very slowly to an average sample of the material. When once a few points on the curves had been obtained the next point could usually be predicted to within 5 kV, and thus the starting point for further tests was ascertained. After the application of the selected voltage for 1 minute, the high-tension voltage was increased by approximately 1 000 volts by adjusting the field of the alternator. All further increases were made in steps of 1 000 volts and all were maintained for 1 minute.

Throughout the paper, where the rate of application of the voltage is not specially mentioned or where it is referred to as standard, or as being raised slowly, it is to be understood that the voltage recorded is that which will produce breakdown at the end of approximately 1 minute. When it is stated that the voltage was raised rapidly it is to be understood that breakdown took place after about 5 seconds.

(*e*) *Thermal capacity of the electrodes.*—As the conditions in an electrical machine are such that heat flows from the metal parts to the insulation, it is desirable that the electrodes employed for test purposes should have both low thermal conductivity and low thermal capacity. Throughout this investigation all electrodes were made of an asbestos composition and covered with 0·005 inch soft copper foil.

(*f*) *Size and shape of the electrodes.*—The larger the area of the electrode the lower the apparent electric strength of the insulation. As the principal object of these tests was to determine the effect of temperature upon the electric strength of the various materials, the area of the electrode was of little importance as long as it was kept the same throughout. The approximate area of all electrodes used was 2 square inches, and the figures quoted are the average of a number of independent determinations. With electrodes having areas of the same magnitude as the area of insulation under stress in a large machine lower values would have been obtained, and consequently the figures quoted must be reduced before they can be used in the design of electrical machinery.

As sharp edges are so frequently unavoidable in the metal parts of electrical machinery, it was not considered necessary to adopt any special radius on the edge of the electrodes. The blocks of asbestos composition were cut with square edges, and when covered with the soft copper foil were still square but not as sharp as the edges of the punchings in an electrical machine often

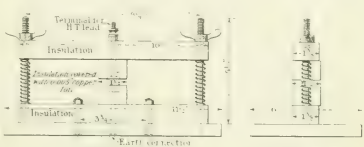

Fig. 1.

are. The top and bottom electrodes were usually of the same size and shape and placed exactly opposite one another. For flat sheets, flat-faced electrodes were used; for cylinders, electrodes were made of the same curvature as the outside and inside surfaces of the cylinder respectively, so that good contact was assured over the whole area of the electrode.

When tests were carried out on damp materials it was found that at certain initial temperatures the I^2R heating was sufficient to volatilize some of the moisture. The expansion produced by the conversion of the water into steam then caused the insulation to swell. In the case of micarta this separated the layers of paper to such an extent as appreciably to increase the distance between the electrodes, with the result that the apparent breakdown voltage was higher than it should be. To overcome this difficulty the samples and electrodes were mounted in a jig (one of which is shown in Fig. 1) and after placing the insulation in position the $\frac{1}{2}$ inch wing nuts were screwed handtight. The application of this mechanical pressure was considered justifiable, since insulating materials when employed in practice have always to be wedged tight to prevent movement of the conductors.

(*g*) *Moisture content.*—The electric strength of absorptive materials is very largely influenced by the quantity

of moisture contained in the fibres. Electrical machinery has frequently to operate in places where the relative humidity of the air is 100 per cent for considerable periods. To reproduce these conditions during this investigation, tests were carried out on samples which had been suspended for two or three days in a large wooden box having at the bottom a shallow tray containing water. The relative humidity was thus kept at 100 per cent and the temperature of the air was about 23° C. Other samples of each of the materials studied were suspended in an oven and maintained at a temperature of 80° to 90° C. for two or three days. It was considered that if the humidified samples were tested in an electrically heated oven, in which the humidity would naturally be low, there would be the possibility of most of the moisture being driven off whilst the sample was warming up to the temperature of the oven. As the large mass of insulation enclosed by the metal portions of an electrical machine cannot so readily get rid of its moisture, it was considered desirable to place a tray of water in the oven so that the air should always have a relative humidity of 100 per cent at the oven temperature. From the above it will be seen that for each material there are four desirable conditions of test, i.e. tests on the dried material (1) in dry air and (2) in damp air, and (3) and (4) similar tests on the humidified material.

(*h*) *Tests in air or oil.*—When tests are carried out under oil there is less concentration of the dielectric flux at the edges of the electrodes, and when such tests are carried out at the temperature of the air the breakdown voltage is usually higher than with similar tests in air. At higher temperatures, particularly in the case of damp samples, those tested in air lose some of their absorbed moisture, whilst those tested in oil cannot do so unless the temperature of the oil exceeds 100° C. Consequently, tests carried out under oil on damp samples usually show a lower electric strength than similar tests carried out in air on the same material. Most of the materials studied are employed both in air and in oil-immersed apparatus and it was therefore considered desirable to conduct tests as far as possible in air and also in oil. This increases the number of desirable test conditions to six, i.e. tests on the dried material (1) in dry air, (2) in damp air and (3) in oil, and similar tests on the humidified material.

As the intention was to obtain temperature/voltage curves from 30° C. to 100° C., and as different thicknesses and different qualities of each material required investigation, it would have taken too long to carry out the 6 conditions of test in every case. The actual conditions were chiefly decided by the use to which the particular insulation was put in practice, whilst in some cases curves were obtained only for (*a*) dried materials tested in dry air, and (*b*) humidified materials tested in oil. These two latter conditions, it was found, gave the highest and lowest electric strengths, respectively.

(3) Apparatus Employed.

The test conditions were standardized in accordance with the remarks made in Section (2), and the air tests were carried out in a double-wall sheet-iron oven, the general arrangement and dimensions of which are shown in Fig. 2. The heating units were distributed ove the bottom of the oven, and a sheet of $\frac{3}{16}$ inch Bakelit Dilecto was placed 3 inches from the sides and back o the oven. These barriers not only produced definit convection currents in the air but prevented the to electrode from flashing-over to the sides of the oven a high voltages.

The tests under oil were carried out in an open-to tank approximately 3 ft. × 2 ft. 6 in. × 3 ft. hig Grid resistances were placed at the bottom of the tan and the natural circulation of the oil, together with th large thermal capacity of so large a quantity of oi enabled a steady temperature to be maintained durin the tests. A transformer oil of ordinary grade wa employed, having the following characteristics :- Specific gravity at 15° C.= 0·85 ; viscosity (Redwoo at 20° C. = 30 ; specific heat at 20° C. = 0·44 ; breal

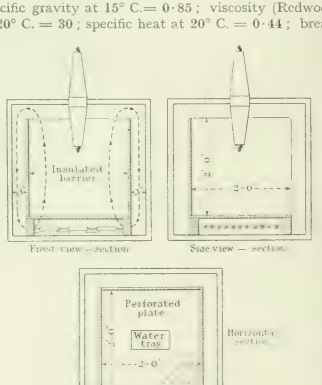

FIG. 2.

down voltage = 14 000 volts when tested between hor zontal needle points spaced $\frac{1}{8}$ inch apart.

Even when the test conditions and apparatus we standardized as completely as possible, it was foun that as so many variables entered into tests of th nature it was impossible to obtain a high degree precision. Consequently it was decided to take t average of a relatively large number of tests, and t figures contained in the following tables, and tho from which the curves have been plotted, are t average of from 3 to 10 independent determinatio In all cases a fair curve has been drawn through t average values, but to make the diagrams as clear possible the actual points have been taken out.

(4) Tests on Papers.

Thin papers are used in the electrical industry f the manufacture of micarta ; as a backing for mic between layers of winding ; and for insulating cabl

etc. Six different papers which were used for most of the above purposes were selected for this investigation. The characteristics of these papers are shown in Table 1.

TABLE 1.

Sample No.	Thickness	Porosity *	Description of Paper
	in.		
1	0·0025	3	Grease-proof
2	0·0024	2	Grease-proof
3	0·0055	17	Wood pulp
4	0·0030	70	Kraft
5	0·0050	2	Parchmentized
6	0·0020	26	Sulphite

* Determined by the rate of flow of air through a sample of the paper.

Temperature/voltage curves were obtained for each of these papers for all the test conditions given above. As figures were required for a total thickness of $\frac{1}{16}$ inch

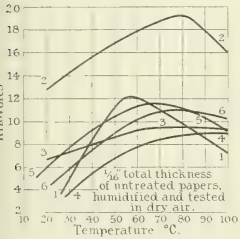

FIG. 3.

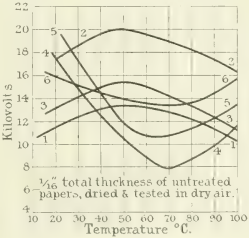

FIG. 4

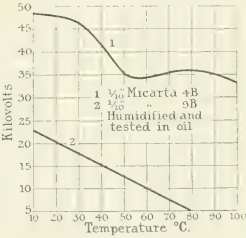

FIG. 5.

of all the insulating materials tested, a number of sheets were tested in series so as to make the thickness as nearly as possible $\frac{1}{16}$ inch. When testing the humidified samples it was found that at the standard rate of application of the voltage the leakage currents through the material produced appreciable drying out and so raised the breakdown voltage. It was therefore decided in certain cases to carry out two series of tests on the humidified samples. In one series the voltage was raised sufficiently rapidly to prevent any appreciable drying out, and in the other series the voltage was raised at the standard rate, some drying-out taking place in most cases. Figs. 3 and 4 show some of the curves obtained when the voltage was applied slowly. The curves obtained on the humidified papers showed that the electric strength when damp was very different, but the presence of the moisture so complicated matters that the nature of the variation in the electric strength could not be definitely determined. Several series of check tests were taken and the averages of all these results obtained at 30° C. and 100° C. are shown in Table 2.

The curves obtained on the dried papers were much more consistent and showed some remarkable differences in the electric strength of the different papers. The averages of all these tests obtained at 30° C. and 100° C. are also given in Table 2, from which it will be noted that the results obtained in oil are much higher than those obtained in air. This is probably due to the rapid absorption of the oil by the moisture-free capillary tubes in the paper. In the case of the humidified papers the moisture in the capillary tubes apparently prevented the oil from entering, although both damp and dry papers were given every opportunity of becoming saturated with oil before a reading was taken. Table 3 shows the percentage increase or decrease in the breakdown voltage at 100° C. computed on that at 30° C. From these figures it would appear that the following facts can be deduced :—

(*a*) When damp papers are tested in air the electric strength at 100° C. may be higher than that when tested cold. This is, of course, due to evaporation of some of the moisture, which takes place even when the paper is surrounded by damp air.

(*b*) When damp papers are tested in oil the electric strength at 100° C. may be higher or lower than that when tested cold. This depends on whether the voltage is raised sufficiently slowly to permit of the moisture being driven out through the oil. Under the conditions in which the insulation is placed in, say, an oil-immersed transformer, and when the voltage is raised at the usual rate for the high-tension test, it would appear that the electric strength of damp paper when hot would certainly be lower than that of the same material when tested cold.

(*c*) When dry papers are tested in air or in the oil the electric strength at 100° C. would appear always to be lower than when cold, particularly in the case of tests carried out in oil.

In Table 4 the results which were obtained by slow and rapid application of the voltage have been averaged together so as to obtain values of more universal application. In this table the tests on the damp samples have still been kept separate from those on the dried samples. In practice the degree of dryness of the papers is probably

TABLE 2.

Thin Papers.

Sample Number	Condition *	B.D.V. when Tested at 30° C. in					B.D.V. when Tested at 100° C. in				
		Dry Air	Damp Air		Oil		Dry Air	Damp Air		Oil	
		Rate of Application of Voltage					Rate of Application of Voltage				
		Slow	Rapid	Slow	Slow	Rapid	Slow	Rapid	Slow	Slow	Rapid
		kV	kV	kV	kV	kV	kV	kV	kV	kV	kV
1	H	8·8	6·5	3·8	6·0	6·0	10·55	13·6	12·7	10·6	4·0
2	H	15·35	11·2	8·9	14·0	15·0	16·55	17·0	18·5	27·0	25·3
3	H	7·5	5·4	7·0	4·0	5·3	10·5	10·8	10·1	13·3	2·3
4	H	5·0	4·8	4·8	6·8	6·C	9·8	10·6	10·6	11·0	2·5
5	H	8·9	7·2	8·7	11·8	13·3	11·7	14·0	12·7	13·5	17·7
6	H	7·2	4·8	3·4	6·0	8·0	9·5	8·8	11·9	1·0	1·0
Average	H	8·8	6·6	6·1	8·1	8·9	11·4	12·4	12·7	12·8	8·8
1	D	16·3		16·8	66·0	—	13·0		17·5	31·0	—
2	D	19·7	—	20·0	65·0	—	18·2		20·4	55·0	—
3	D	14·6	—	15·8	42·0	—	12·7		13·4	28·4	—
4	D	16·0	—	12·4	53·0	—	12·2	—	12·2	31·0	—
5	D	17·0	—	15·5	46·0	—	13·7	—	14·6	40·0	—
6	D	17·6	—	17·5	64·0	—	16·5	—	15·2	32·0	—
Average	D	16·8	—	16·3	56·0	—	14·4	—	15·5	36·0	—

* H = humidified; D = dried.

TABLE 3.

Thin Papers.

Sample Number	Condition *	Percentage Variation in B.D.V. at 100° C. from that at 30° C. in				
		Dry Air		Damp Air	Oil	
		Slow	Rapid	Slow	Slow	Rapid
		Per cent	Per cent	Per cent	Per cent	Per cent
1	H	+ 19	+ 109	+ 235	+ 76	— 33
2	H	+ 8	+ 51	+ 109	+ 93	+ 68
3	H	+ 40	+ 100	+ 44	+ 232	— 56
4	H	+ 96	+ 121	+ 120	+ 61	58
5	H	+ 31	+ 94	+ 46	+ 14	+ 33
6	H	+ 32	+ 83	+ 250	83	— 87
Average	H	+ 30	+ 88	+ 108	+ 58	— 11
1	D	— 20		+ 4	— 53	—
2	D	— 7·6	—	+ 2	— 15	—
3	D	— 13	—	+ 15	— 32	—
4	D	— 23	—	+ 16	— 41	—
5	D	— 19	—	+ 6	— 13	—
6	D	— 6	—	— 13	— 50	—
Average	D	— 14	—	— 5	— 35	—

* H = humidified; D = dried.

somewhere between the two extreme conditions produced for these tests. To adjust for this as far as possible the humidified and dry values have been averaged together in Table 5, the last line of which gives the mean of all the 6 papers for the conditions stated. The figures giving the average breakdown voltage (B.D.V.) of the 6 papers for all air and oil tests at 30° C. and 100° C. respectively are of particular interest as they represent the average result of a very large number of individual determinations. These latter figures will be used later to compare untreated thin papers with the other materials tested during this investigation.

(5) Tests on Micarta.

By the term "micarta" is implied a material composed of layers of paper stuck together with a varnish which fulfils the function of :—

(*a*) Bonding the paper into a solid material; and
(*b*) Improving the electric strength of the paper.

Several different kinds of paper are employed in the electrical industry for the manufacture of micarta; some of these are of the grease-proof type with low porosity, whilst others are of a more absorptive nature, and in appearance closely resemble a thin sheet of ordin-

Table 4.

Breakdown Voltage of $\frac{1}{16}$ inch Total Thickness of Papers Tested under Conditions Stated.

Sample Number	Condition*	Average of all Tests in Air		Average of all Tests in Oil		Average of all Tests	
		At 30° C.	At 100° C.	At 30° C.	At 100° C.	At 30° C.	At 100° C.
		kV	kV	kV	kV	kV	kV
1	H	6·3	12·2	6·0	7·3	6·2	9·9
2	H	11·9	17·4	14·5	26·2	13·2	21·8
3	H	6·9	10·2	4·6	7·8	5·7	9·0
4	H	5·9	10·3	6·4	6·7	6·1	8·5
5	H	8·5	12·6	12·6	15·6	10·5	14·1
6	H	5·2	10·4	7·0	1·0	6·1	5·6
Average	H	7·5	12·2	8·5	10·8	8·0	11·0
1	D	16·6	15·3	66·0	31·0	41·3	23·1
2	D	20·0	19·3	65·0	55·0	42·5	37·1
3	D	15·2	13·1	42·0	28·4	28·6	20·7
4	D	14·2	12·3	53·0	31·0	33·6	21·6
5	D	16·3	14·2	46·0	40·0	31·1	27·1
6	D	17·6	15·9	64·0	32·0	40·8	24·0
Average	D	16·6	14·9	56·0	36·2	36·3	25·6

* H = humidified; D = dried.

Table 5.

Average of all Tests on $\frac{1}{16}$ inch Total Thickness of Dry and Damp Papers.

Sample Number	Average of Tests in Dry and Damp Air, B.D.V.		Average of Tests in Oil, B.D.V.		Average of all Tests, B.D.V.	
	At 30° C.	At 100° C.	At 30° C.	At 100° C.	At 30° C.	At 100° C.
	kV	kV	kV	kV	kV	kV
1	11·4	13·6	36·0	19·2	23·7	16·1
2	15·9	19·3	39·8	40·6	27·8	29·5
3	11·0	11·7	23·3	18·1	17·2	14·9
4	10·0	11·3	29·7	18·9	19·9	15·1
5	12·4	13·4	29·3	27·8	20·8	20·6
6	11·4	13·1	35·5	16·5	23·5	14·8
Average	12·0	13·7	32·2	23·5	22·2	18·5

ary brown paper. As a rule the thickness of the papers employed for making micarta lies between 0·002 inch and 0·005 inch.

The bonds employed are as numerous as the papers, but fall naturally into two classes :—

(*a*) Varnishes, the chief constituents of which are natural gums, such as shellac, copal, etc.

(*b*) Varnishes, the chief constituents of which are synthetic gums, such as bakelite and other phenol-formaldehyde condensation products.

Originally, micarta appears to have been placed on the market as a substitute for micanite (mica splittings stuck together with shellac), and the close resemblance sheets, and specially formed shapes such as U shape rectangular troughs, etc.

Tests were carried out on between 20 and 30 differe samples, most of which were in the form of cylinde of an internal diameter of 8 inches, the remainder bei in the form of flat sheets.

Several of the thin papers [test results of which a given in Section (4)] were used in the manufacture some of the samples of micarta, and the numbers giv to the papers in Tables 6, 7 and 8 correspond to t numbers given to the same papers in Section (4).

Bonds A to C inclusive were made from synthet gums, whilst bonds D to F inclusive were compos of various combinations of natural gums. As in previo

TABLE 6.

Micarta.

Paper Used	Bond Used	Condition*	Thickness	B.D.V. and Electric Strength at 30° C. tested in Dry Air		Damp Air		Oil		B.D.V. and Electric Strength at 100° C. tested in Dry Air		Damp Air		Oil	
				B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength
			in.	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil
No. 1	D	H	1/10	—	—	34	340	—	—	—	—	8·4	84	—	—
No. 1	D	H	1/8	—	—	39	310	—	—	—	—	17	136	—	—
No. 1	E	H	1/16	—	—	34	540	—	—	—	—	12	190	—	—
No. 1	E	D	1/4	—	—	—	—	70	280	—	—	—	—	15	60
No. 2	B	D	1/10	—	—	—	—	50	500	—	—	—	—	27	270
No. 2	L	D	1/8	—	—	—	—	50	370	—	—	—	—	20	160
No. 2	E	D	1/4	—	—	—	—	81	325	—	—	—	—	40	160
No. 4	D	H	1/10	—	—	35	350	—	—	—	—	10	100	—	—
No. 4	E	D	1/8	—	—	—	—	47	380	—	—	—	—	15	121
No. 4	C	D	1/8	—	—	—	—	46	365	—	—	—	—	32	256
No. 4	B	H	3/16	—	—	70	375	86	470	—	—	22	118	60	320
No. 7	A	H	1/16	—	—	25	400	—	—	—	—	9	143	—	—
No. 8	D	D	1/8	—	—	—	—	65	520	—	—	—	—	30	240
No. 8	A	D	1/8	—	—	—	—	40	320	—	—	—	—	70	560
No. 8	A	F	1/8	—	—	—	—	44	327	—	—	—	—	34	270
No. 9	D	D	1/10	—	—	41	410	71	710	—	—	21	210	16	160
No. 9	D	H	1/10	15·6	156	13·5	135	18·0	180	9·0	90	Conducting		Conducting	
No. 9	A	D	1/10	—	—	38	380	62·5	625	—	—	14	140	14	140
No. 9	A	H	1/10	14·2	142	10·7	107	16·5	165	5·5	55	Conducting		Conducting	
No. 10	F	D	1/8	—	—	27·5	220	48	387	—	—	10·6	85·0	6·2	49
No. 10	F	H	1/8	—	—	26	207·5	45	363	—	—	4·7	37·5	6·2	49

* D = dehydrated; H = humidified; F = prolonged vacuum drying.

of the two names has led to much confusion, which has been intensified by the fact that certain varieties of micarta are manufactured which contain a number of layers of mica in addition to the layers of paper. By placing the mica in the centre portion and the paper on the outsides, the mica is protected from flaking off (which is one of the objections to micanite), and a material having both good mechanical and good electrical properties is produced. In this investigation all such materials containing mica were considered to be mica products and are dealt with in a later section of the paper.

All results referring to micarta were obtained on materials composed solely of paper and varnish and will be referred to throughout by the term "micarta." This material is employed in the manufacture of electrical machinery in the form of tubes, cylinders (i.e. tubes having a greater internal diameter than 3 inches), tests, temperature/voltage curves were obtained on bo dry and humidified specimens, but in only two cas was a complete series of tests carried out in dry a damp air and oil.

As micarta is largely employed for the insulati of oil-immersed apparatus, the majority of the tes were conducted in oil. Figs. 5, 6 and 7 show typic results obtained during the tests carried out in o whilst Fig. 8 gives one set of results obtained in a From these curves and from the figures quoted in t tables it will be seen that the decrease in breakdo voltage with increase in temperature is very rapid the case of all the samples of micarta tested.

The breakdown voltages at 30° C. and 100° C. for number of commercial grades of micarta are summariz in Table 6. As all these micartas are used in some for or other by the electrical industry, it was considered th the average of all these tests would enable a gener

TABLE 7.

Breakdown Voltage of Various Samples of Micarta reduced to a Thickness of $\frac{1}{16}$ inch.

Piece Tested	Bond Tested	Conditions*	B.D.V. at 30° C. tested in:			Soaked 24 hours, tested in:		
			Dry Air	Damp Air	Oil	Dry Air	Damp Air	Oil
			kV	kV	kV	kV	A	A
No. 1	D	H	—	20	—	—	7	—
No. 1	D	H	—	20	—	—	7	
No. 1	E	H	—	34	—	—	12	—
No. 1	E	D	—	—	24	—	—	5·5
No. 2	B	D	—	—	32	—	—	18
No. 2	E	D	—	—	30	—	—	11·5
No. 2	E	D	—	—	28	—	—	11·5
No. 4	D	H	—	24	—	—	7	—
No. 4	E	D	—		30	—	—	8·5
No. 4	C	D	—	—	23	—	—	18
No. 4	B	H	—	31	36	—	9·5	22
No. 7	A	H		25	—	—	9	—
No. 8	D	D	—	—	35	—	—	16
No. 8	A	D	—	—	24	—	—	4
No. 8	A	VD	—	—	25	—		19
No. 9	D	D		26	46	—	14	12
No. 9	D	H	11	9	13	7	Conducting	Conducting
No. 9	A	D	—	25	42	—	10	10
No. 9	A	H	9·5	7·5	12	4·5	Conducting	Conducting
No. 10	E	D	—	19	28	—	6	4
No. 10	E	H	—	19	28	—	3·5	4

* D = dried; H = humidified; VD = vacuum dried.

TABLE 8.

Average of all Tests on Micarta reduced to a Thickness of $\frac{1}{16}$ inch.

Piece Tested	Bond Tested	Average of all Tests in Dry and Damp Air, 1 D.V.		Average of all Tests in Oil, B.D.V.		Average of 72 hour B.D.V.	
		At 30° C.	At 100° C.	At 30° C.	At 100° C.	At 30° C.	At 100° C.
		kV	kV	kV	kV	A	A
No. 1	D	20	7	—	—	20	7
No. 1	E	34	12	24	5·5	29	8·7
No. 2	B	—	—	32	18	32	18
No. 2	E	—	—	29	11·5	29	11·5
No. 4	D	24	7	—	—	24	7
No. 4	E	—	—	30	8·5	30	8·5
No. 4	C	—	—	23	18	23	18
No. 4	B	31	9·5	36	22	33·5	15·7
No. 7	A	25	9	—	—	25	9
No. 8	D	—	—	35	16	35	16
No. 8	A	—	—	24·5	11·5	24·5	11·5
No. 9	D	15·3	7	28	6	21·7	6·5
No. 9	A	14	4·8	27	5	20·5	4·9
No. 10	F	19	4·7	28	4	23·5	4·4
Average of bonds A, B and C		23·4	7·8	38·5	15	26·3	12·9
Average of bonds D, E and F		22·5	7·5	29	8·6	26·3	8·8
Average of all bonds		27·9	7·7	28·7	11·8	26·3	10·8

opinion to be formed of the effect of heat on the electric strength of this material. From Table 6 it will be observed that these tests were carried out on thicknesses ranging from $\frac{1}{16}$ inch to $\frac{1}{32}$ inch. In order to permit of an easier comparison between the different grades and also between the other materials tested, the breakdown voltages of the samples listed in Table 6 have been calculated for a thickness of $\frac{1}{16}$ inch in Table 7. This was accomplished by means of thickness/voltage curves taken at 30° C. and 100° C. on representative samples of each class of material tested. The average of the dry

gum micartas were all found to be extremely soft an flexible.

Referring to the last line of Table 8, it will be see that the average of all the tests on all bonds and paper investigated clearly shows that whilst the addition o the bond to the paper makes the electric strength o micarta at 30° C. higher than that of the same thickne of unvarnished paper, the reverse is the case when th materials are tested at 100° C. At first sight this i very surprising, but recent researches on gums offer a explanation of this phenomenon.

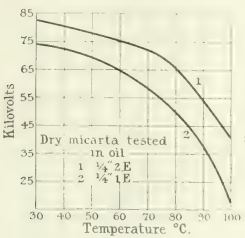

FIG. 6.

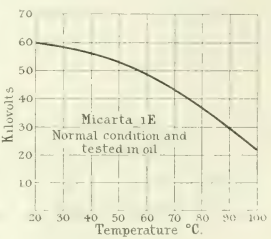

FIG. 7.

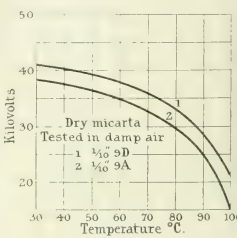

FIG. 8.

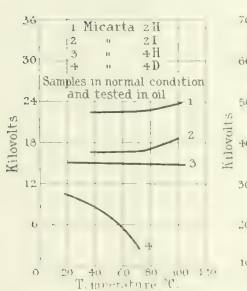

FIG. 9.

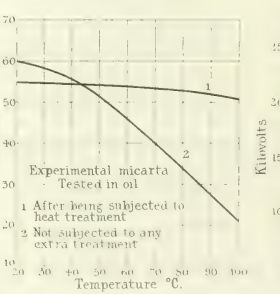

FIG. 10.

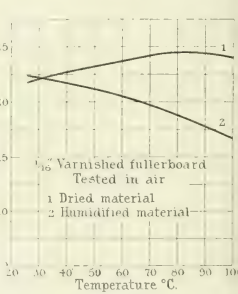

FIG. 11.

and damp tests on the various grades of micarta are shown in Table 8, and the last three lines of this table contain the mean of all the tests listed in Table 6.

As an equal number of tests under similar conditions were not made on the synthetic-gum micartas and the natural-gum micartas, no definite conclusions can be drawn from the average of bonds A, B and C, and D, E and F, respectively. Speaking generally, however, it would appear that the synthetic bonds have a higher electric strength than the natural-gum bonds at 100° C., and this is probably partly due to the fact that at this temperature the synthetic-gum micartas retain most of their initial mechanical strength, whilst the natural-

Both natural and synthetic gums are extremel complex chemical mixtures; when either of these type of gums is heated destructive distillation takes place Some of the constituents given off consist of organi acids, and water is also often one of the distillates Even at 80° C. certain gums give off small quantitie of highly acid distillates, whilst at 100° C. practically a the gums which have been employed for the manufactur of micarta produce acid distillates. Even if the quantit produced is extremely small its acid nature and th fact that it is evolved inside the insulation may con ceivably result in a very appreciable decrease in electri strength. To those acid distillates is attributed th

rapid decrease in electric strength shown in Tables 6, 7 and 8.

The materials and process for the manufacture of micarta offer a most profitable field for further research, and in this connection results obtained on some experimental bonds not previously used for micarta are shown in Fig. 9. Even with the bonds at present employed much can be done by suitable heat treatment to remove the acid distillates and so raise the electric strength at 100° C. Some results obtained in this connection are shown in Fig. 10.

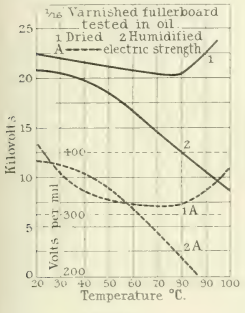

Fig. 12

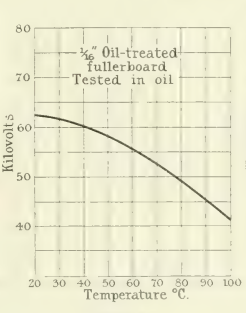

Fig. 13

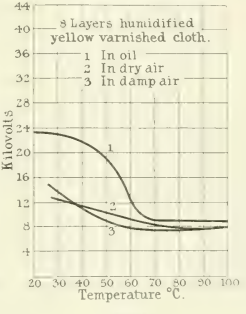

Fig. 14

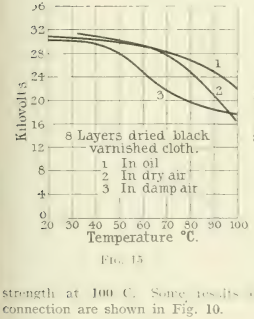

Fig. 15

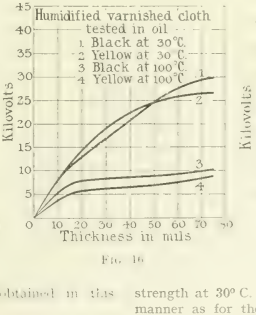

Fig. 16

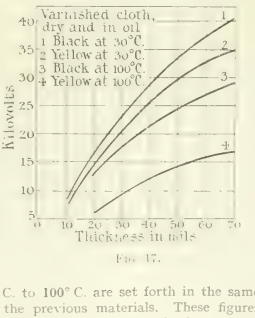

Fig. 17.

(6) Fullerboard.*

Tests were carried out on untreated, varnish-treated, and oil-impregnated fullerboards. In all cases the nominal thickness was $\frac{1}{16}$ inch, and, when the treatment increased the thickness, the actual thickness was measured in the immediate vicinity of the breakdown, and the electric strength calculated on this value. In most cases tests were carried out on both dried and humidified samples of the same material. As untreated and varnished fullerboard is used both in air and in oil, samples were tested in dry air, damp air and oil. Oil-impregnated fullerboard, however, is used only in oil-immersed apparatus, and consequently tests were carried out only in oil.

Figs. 11, 12 and 13 show some of the results obtained. In Table 9 the breakdown voltage and the electric strength at 30° C. to 100° C. are set forth in the same manner as for the previous materials. These figures clearly illustrate that the electric strength of a material of the nature of fullerboard may vary over a very wide range, depending on the treatment it has received and the condition of the sample at the time of test. Thus when untreated fullerboard of a thickness of $\frac{1}{16}$ inch which had previously been exposed to a damp atmosphere was tested in oil, the electric strength at 30° C. was of the order of 110 volts per mil, only. If the same material is dried and impregnated with a mineral oil, the electric strength at 30° C. when tested under the same conditions may be as high as 1 000 volts per mil.

* By the term "fullerboard" is meant a good quality paper board known in the electrical industry as fullerboard, pressboard, or press-spahn.

The corresponding values when the samples are tested in oil at 100° C. are 48 and 610, respectively. These facts are of the utmost importance in the manufacture of electrical machinery, particularly when the thickness of the insulation used is such as to impose, during the high-voltage pressure-test, stresses near the breakdown voltage of the dielectric. As the thoroughness of the electric strength to decrease, the average decrease bei anything from 39 per cent of the electric strength 30° C. The average figures for fullerboard deduc from these tests are given in Table 11. The inclusi of figures obtained on untreated and treated fullerboa results in the average figure being considerably low than the maximum figure obtained on the mineral-

TABLE 9.

Fullerboard.

Treatment of Sample	Sample Number	Condition *	Nominal thickness	B.D.V. and Electric Strength at 30° C. in Oil				B.D.V. and Electric Strength at 100° C. in Oil							
				Dry Air		Damp Air		Oil		Dry Air		Damp Air		Oil	
				B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength
			in.	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil
Untreated	1	H	1/16	7·5	120	5·0	80	7·0	110	11·0	180	9·5	150	3·0	4
Ditto	2	D	1/16	18·8	300	19·5	312	24·5	390	19·7	315	13·0	210	19·0	30
Varnished both sides with linseed-oil varnish; edges unvarnished	3	H	1/16	21·9	342	24·0	382	23·9	382	17·5	280	16·3	260	7·5	12
Ditto	4	D	1/16	22	352	26·6	136	23·0	368	24·4	388	23·5	376	23·3	37
Impregnated with vegetable oil	5	H	1/16	—	—	—	—	25·0	400	—	—	—	—	11	17
Ditto	6	N	1/16	—	—	—	—	—	—	—	—	—	—	—	—
Impregnated with mineral oil	7	N	1/16	—	—	—	—	61	1000	—	—	—	—	41	61

* D = dried; H = humidified; N = normal.

TABLE 10.

Fullerboard.

Treatment of Sample	Sample Number	Condition *	Nominal Thickness	Increase or Decrease on B.D.V. and Electric Strength at 100° C. Immediately after Drying at									
				Dry Air			Damp Air			Oil			
				B.D.V.	Elec. Strength	Increase or Decrease	B.D.V.	Elec. Strength	Increase or Decrease	B.D.V.	Elec. Strength	Increase or Decrease
			in.	kV	V/Mil	Per cent	kV	V/Mil	Per cent	kV	V/Mil	Per cent
Untreated	1	H	1/16	+ 3·5	+ 60	— 16·6	+ 4·5	+ 70	— 90	— 4·0	— 62	— 57
Ditto	2	D	1/16	— 0·9	+ 50	+ 4·78	6·5	— 94	— 33·3	— 5·5	— 90	— 22
Varnished both sides with linseed-oil varnish; edges unvarnished	3	H	1/16	— 4·4	— 62	— 20·2	7·7	122	— 32·1	— 16·4	— 262	— 68
Ditto	4	D	1/16	— 2·4	— 36	+ 10·9	— 3·1	— 60	— 11·6	+ 0·3	+ 4	+ 1
Impregnated with vegetable oil	5	H	1/16	—	—	—	—	—	—	— 14	— 230	— 56
Ditto	6	Not H	1/16	—	—	—	—	—	—	—	—	—
Impregnated with mineral oil	7	N	1/16	—	—	—	—	—	—	— 20	— 390	— 33
Ditto	8	Not H	1/16	—	—	—	—	—	—	—	—	—
Average		N	1/16	+ 0·6	— 21	+ 10·5	3·2	— 74	3·2	— 9·9	172	— 39

* D = dried; H = humidified; N = normal.

treatment of these materials results in such a large variation in their electric strength, it is quite conceivable that apparatus which with correct treatment might have had an ample factor of safety on the test voltage, may not, as the result of incorrect treatment, be able to withstand the test voltage.

From Table 10 it will be seen that, whilst in certain cases the electric strength was slightly higher at 100° C. than at 30° C., the tendency on the whole is for the impregnated material. This emphasizes the fact th when using a material of the nature of fullerboard, t electric strength depends even more on the thoroughne of the treatment than upon the initial electric streng of the material previous to treatment.

Comparing the average figures in the last line Table 11 with corresponding figures for the oth materials dealt with, it is seen that, on the who fullerboard would appear to be a more suitable mater

for high temperatures than micarta, and, as would be expected, it has approximately the same electric strength at 100° C. as the thin papers previously tested. At lower temperatures the effect of the treatment given to the fullerboard is more pronounced, resulting at 30° C. in the electric strength being about

on the outside of the varnished cloth was used as one electrode, and the brass tube as the other electrode. Figs. 14 and 15 show some of the results obtained on both yellow and black varnished cloth of a thickness of 0·007 inch. In Table 12 the comparison is made between the breakdown voltage and electric strength

TABLE 11.

Average Breakdown Voltage for Dry and Damp Samples of Fullerboard, Calculated for a Nominal Thickness of $\frac{1}{16}$ *inch in all cases.*

Sheet Number	Average of Tests in Dry and Damp Air B.D.V.		Average of Tests in Oil. B.D.V.		Average of all Tests. B.D.V.	
	At 30° C.	At 100° C.	At 30° C.	At 100° C.	At 30° C.	At 100° C.
	kV	kV	kV	kV	kV	kV
1	6·25	10·25	7·0	3·0	6·5	6·6
2	19·0	16·5	24·5	19·0	21·7	17·7
3	23·0	17·0	23·9	7·5	23·4	12·2
4	24·3	24·0	23·0	23·3	23·5	23·5
5	-	—	25·0	11	25·0	11·0
7			61·0	41·0	61·0	41·0
Average	18·0	16·8	27·0	17·5	26·7	18·6

TABLE 12.

Varnished Cloth.

Material	Sheet Number	Condition	Total Thickness	B.D.V. and Electric Strength at 30° C. tested in: Dry Air B.D.V.	Dry Air Elec. Strength	Damp Air B.D.V.	Damp Air Elec. Strength	Oil B.D.V.	Oil Elec. Strength	B.D.V. and Electric Strength at 100° C. tested in: Dry Air B.D.V.	Dry Air Elec. Strength	Damp Air B.D.V.	Damp Air Elec. Strength	Oil B.D.V.	Oil Elec. Strength
			in.	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil
5 layers of 0·007 in. yellow varnished cloth	1	N	0·034	14·8	435			-	-	8·4	245	—	—	—	—
7 layers of 0·007 in. yellow varnished cloth	2	N	0·047	20·1	430	-			-	10·6	225	—	—	—	—
7 layers of 0·007 in. yellow varnished cloth	3	N	0·049	20·2	410	- -			-	9·5	193	-	-		
8 layers of 0·007 in. yellow varnished cloth	4	H	0·050	11·8	235	12·4	248	22·8	456	7·9	158	7·9	158	8·4	168
		D	0·050	31	620	18·2	364	28	560	10	200	9·8	196	13	260
7 layers of 0·007 in. black varnished cloth	5	N	0·049	26·7	545		-	-	-	16·8	344				
8 layers of 0·007 in. black varnished cloth	6	H	0·053	25·7	485	23·4	440	27	510	8·2	154	10	188	12·4	235
		D	0·053	31	585	30·2	570	30·6	580	16·4	310	17·8	330	22·4	420
Average..		N	0·048	22·8	488	21·0	405	27·1	526	10·9	229	10·4	218	14·0	271

D dried; H humidified; N normal.

the same as for micarta, and higher than that of untreated papers.

(7) VARNISHED CLOTH.

The tests on varnished cloth were carried out by wrapping a length of the cloth on a brass tube about 12 inches long by 1 inch outside diameter. The material was tightly wrapped so as to reduce as far as possible the presence of films of air, and was firmly held in place by a layer of cotton tape. A piece of copper foil placed

at 30° C. and 100° C. Tests were made on six different samples taken from six consignments from three different sources. Four of these rolls contained yellow varnished cloth, and the other two were black varnished cloth. Only in two cases, one of yellow cloth and one of black, was it possible to carry out a complete series of tests on dried and humidified samples, in dry air, damp air and oil. From the average figures given at the bottom of Table 12 it will be seen that the average electric strength at 30° C. of all the samples tested is of the

order of 480 volts per mil in dry air, 400 in damp air, and 520 in oil. When the same materials are tested at 100° C. the corresponding electric strengths are 229, 218 and 271 volts per mil. respectively.

Table 13 shows the decrease in breakdown voltage and electric strength between 30° C. and 100° C., and 17 were plotted. From the thickness/voltag curve corresponding to the particular material th breakdown voltages were calculated for a total thick ness of varnished cloth of $\frac{1}{16}$ inch in all case The results obtained are given in Tables 14 and 1 From the average figures in the last line of Table 1

TABLE 13.

Varnished Cloth.

Decrease in B.D.V. and Electric Strength at 100° C. compared with that at 30° C.

Material	Sample Number	Coating*	Thickness	Dry Air		Damp Air		Oil	
				B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength
			in.	kV	V/Mil	Percent	kV	V/Mil	Percent	kV	V/Mil	Percent	kV	V/Mil	Percent
5 layers of 0·007 in. yellow varnished cloth	1	N	0·034	6·4	188	45	-	-	-	-	-	-	-	-	-
7 layers of 0·007 in. yellow varnished cloth	2	N	0·047	9·5	202	47	-	-	-	-	-	-	-	-	-
7 layers of 0·007 in. yellow varnished cloth	3	N	0·049	10·7	218	53	-	-	-	-	-	-	-	-	-
8 layers of 0·007 in. yellow varnished cloth	4	H	0·050	3·9	74	33	4·5	90	36	14·4	287	63	-	-	-
		D	0·050	21	420	68	8·4	168	46	15	300	54	-	-	-
7 layers of 0·007 in. yellow varnished cloth	5	N	0·049	9·9	202	37	-	-	-	-	-	-	-	-	-
8 layers of 0·007 in. black varnished cloth	6	H	0·053	17·5	330	68	13·4	253	57	14·6	275	54	-	-	-
		D	0·053	14·6	275	47	12·4	234	41	8·2	155	26	-	-	-
Average		N	0·045 (yellow)	10·3	225	49	6·4	129	41	14·7	293	59	-	-	-
		N	0·051 (black)	10·9	270	51	12·9	243	49	11·4	215	40	-	-	-
		N	0·048 (both)	10·5	245	50	9·6	186	45	13·1	254	50	-	-	-

* D = dipped; H = humidified; N = normal.

TABLE 14.

Varnished Cloth.

B.D.V. and Electric Strength at 30° C. | Calculated for $\frac{1}{16}$ in. Thickness at 100° C. in

Sample Number	Coating*	Thickness	Dry Air		Damp Air		Oil		Dry Air		Damp Air		Oil	
			B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength
		in.	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil
1	N	1/16	23·2	370	-	-	-	-	13·0	208	—	- -	-	-
2	N	1/16	22·9	366	-	-	-	-	11·9	190	-	- -	-	-
3	N	1/16	25·3	405	- -	-	- -	-	11·0	176	- -	—	—	—
4	H	1/16	13·4	214	14·1	226	26·1	417	7·2	115	7·2	115	7·7	123
	D	1/16	41·6	668	24·5	391	31·0	495	27·7	444	27·1	434	36·0	576
5	N	1/16	37·2	598	-	-	-	-	26·0	417	-	-	-	-
6	H	1/16	28·5	455	25·8	412	28·1	476	7·6	121	7·8	125	9·8	156
	D	1/16	38·5	642	37·6	600	38·0	608	28·8	460	28·7	459	39·0	623

* D = dipped; H = humidified; N = normal.

expressed as a percentage. The last line in this table shows that for the above temperature range the electric strength of varnished cloth decreases by approximately 50 per cent for the average of all conditions of the material, and all conditions of test considered during this investigation. In order that the results obtained on varnished cloth might be compared with results obtained on other materials tested under similar conditions, thickness/voltage curves as shown in Figs. 16 it will be seen that varnished cloth when tested col compares very favourably with the other material already considered, but when tested at 100° C. it i no better electrically than paper or fullerboard, though superior to micarta.

(8) MICA PRODUCTS.

Mica is employed in many different forms for th insulation of electrical machinery. To make thes

tests as complete as possible, investigations were carried out on the following 9 materials, each of which contained mica :—

(i) *Mica cambric.*—This consisted of 1 layer of 0·005-inch untreated cambric, 1 layer of overlapping mica splittings, and 1 layer of 0·001-inch Japanese paper. Total average thickness : 0·010 inch.

(ii) *Flexible mica paper,* consisting of 1 layer of 0·005-inch untreated paper, 2 layers of overlapping mica splittings, and 1 layer of 0·001-inch Japanese paper. Total average thickness : 0·014 inch.

(iii) *Mica varnished cloth,* consisting of 1 layer of 0·005-inch yellow varnished cloth, 2 layers of overlapping mica splittings, and 1 layer of 0·001-inch Japanese paper. Total average thickness : 0·012 inch.

(iv) *Micafolium plate.*—This material consists of 1 layer of overlapping mica splittings stuck by means of shellac varnish on to a piece of 0·002-inch paper, and finished off by brushing an extra coat of shellac over the top of the mica. It is very largely used for the insulation of high-voltage stator bars, insulating tubes, etc. For these tests a number of layers of this material were hot-pressed to form a solid plate.

TABLE 15.

Varnished Cloth.

Average Breakdown Voltage for Dry and Damp Samples of Varnished Cloth. Calculated for thickness of $\frac{1}{10}$ inch in all cases.

Sample Number	Average of Tests in Dry and Damp Air B.D.V.		Average of Tests in Oil B.D.V.		Average of all Tests B.D.V.	
	At 30° C.	At 100° C.	At 30° C.	At 100° C.	At 30° C.	At 100° C.
	kV	kV	kV	kV	kV	kV
1	23·2	13·0	—	—	23·2	13·0
2	22·9	11·9	—	—	22·9	11·9
3	25·3	11·0	—	—	25·3	11·0
4	25·9	17·3	28·5	21·8	27·2	19·5
5	37·2	26·0	—	—	37·2	26·0
6	32·6	18·2	33·0	24·4	32·8	21·3
Average	27·8	16·2	30·7	23·1	28·1	17·1

TABLE 16.

Material	Sample Number	Condition*	Total Thickness	B.D.V. at 30° C. tested in Dry Air			Damp Air			Oil			B.D.V. at 100° C. tested in Dry Air			Damp Air			Oil		
				B.D.V.	Elec. Strength		B.D.V.	Elec. Strength		B.D.V.	Elec. Strength		B.D.V.	Elec. Strength		B.D.V.	Elec. Strength		B.D.V.	Elec. Strength	
			in.	kV.	V./Mil.		kV.	V./Mil.		kV.	V./Mil.		kV.	V./Mil.		kV.	V./Mil.		kV.	V./Mil.	
Mica cambric	1	D	0·062	19·7	319		—	—		22·3	360		22·9	370		—	—		18·4	297	
		H	0·062	18·5	299		—	—		18·0	291		19·9	321		—	—		19·0	307	
Flexible mica paper	2	D	0·054	19·1	354		—	—		32·0	593		21·8	405		—	—		23·5	436	
		H	0·054	23·3	432		—	—		24·3	450		30·2	560		—	—		25·1	471	
Mica varnished cloth	3	D	0·047	28·5	608		—	—		34·7	740		30·0	635		—	—		31·5	672	
		H	0·047	22·8	485		—	—		22·6	481		28·5	608		—	—		27·5	586	
Micafolium plate	4	D	0·063	26	415		—	—		38·5	616		34	544		—	—		30	480	
		H	0·063	29	464		—	—		29	464		28·3	453		—	—		27·6	442	
Mica silk	5	D	0·033	17·5	530		—	—		25·2	762		18·8	570		—	—		19·0	577	
		H	0·033	17·0	516		—	—		19·4	589		18·0	545		—	—		16·0	485	
Hard mica paper	6	D	0·062	33·0	528		—	—		38·5	616		31·5	505		—	—		33·5	535	
		H	0·062	33·0	528		—	—		42·5	672		31·5	505		—	—		38·0	608	
Mica Japanese paper	7	D	0·022	11·5	548		—	—		24	1 090		16·0	762		—	—		15·5	738	
		H	0·016	14·5	690		—	—		17·5	835		15·0	714		—	—		16·0	762	
Flexible micanite	8	N	0·025	26·9	1 053		—	—		26·4	1 055		25·8	1 032		—	—		23·2	928	
			0·040				29·0	725								27·9	698				
Hard micanite plate	9	D	0·063	33	528		—	—		32	512		33·0	528		—	—		32	512	
		H	0·063	39	625		—	—		40	640		34·7	565		—	—		27	432	

* D = dried; H = humidified; N = normal.

(v) *Mica silk*, consisting of 1 layer of 0·002-inch silk, 1 layer of overlapping mica splittings, and 1 layer of 0·001-inch Japanese paper. Total average thickness: 0·008 inch

(vi) *Hard mica paper*.—Micafolium plate (sample iv) consisted of alternate layers of paper and mica. Hard mica paper plate consisted of about $\frac{3}{4}$ mica splittings stuck together with shellac and sandwiched between $\frac{1}{4}$ paper on each side. For these tests, sheets were made up as above having a total nominal thickness of $\frac{1}{16}$ inch.

age values obtained at 30° C. and 100° C. are shown in Table 16. From these results it will be seen that in the case of all the mica products there is far less decrease in the electric strength at high temperatures than was experienced in the case of the fibrous materials. Figs. 18 to 22 inclusive show typical results obtained during these tests.

The average values for the damp and dry samples calculated from thickness/voltage curves (as shown in Fig. 21) for a total thickness of $\frac{1}{16}$ inch in all cases are given in Table 17. Comparing these values with the figures obtained under exactly similar

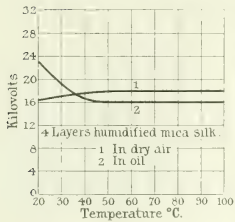

FIG. 18

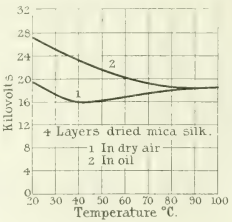

FIG. 19

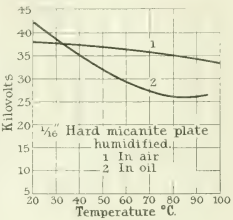

FIG.

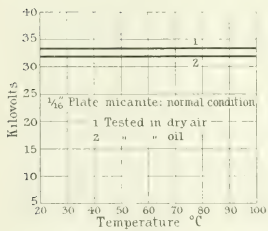

FIG. 21.

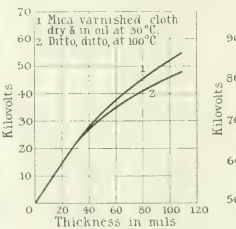

FIG. 22

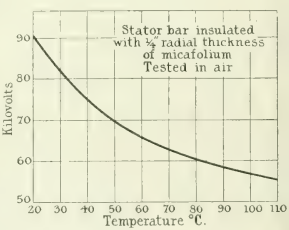

FIG. 23.

(vii) *Mica Japanese paper*.—This consisted of 1 overlapping layer of mica splittings sandwiched with a piece of 0·001-inch Japanese paper on each side and bonded with a flexible sticking varnish. Total average thickness: 0·005 inch.

(viii) *Flexible micanite*, consisting of overlapping layers of mica splittings and a flexible sticking varnish.

(ix) *Hard micanite plate*, consisting of overlapping layers of mica splittings and shellac varnish. This material is finished off by pressing in a steam-heated press.

Temperature/voltage curves were obtained on flat sheets of each of the above 9 materials, and the aver-

conditions on the fibrous materials, it will be seen to what a small extent the electric strength of the mica products decreases with increase in temperature. With some of the materials, however, there is still an appreciable decrease, particularly when they are tested in oil. In this connection it should be remarked that very few of these mica products are actually employed for the manufacture of oil-immersed apparatus, but one of the objects of these tests in oil was to examine the effect of heat on these materials when they were so placed that they could not readily get rid of any moisture or varnish compounds which they were known to contain. During the tests in air the small samples, being freely exposed to the air, could and did evaporate some of the volatile constituents contained in the backing materials or the bonds. As pointed out when dealing

TABLE 17.

Average of all Tests on Mica Products Calculated for a Thickness of $\frac{1}{16}$ inch.

Material	Sample Number	Average of all Tests in Dry and Damp Air, B.D.V.		Average of all Tests in Oil, B.D.V.		Average of all Tests, E.D.V.	
		At 30° C.	At 100° C.	At 30° C.	At 100° C.	At 30° C.	At 100° C.
		kV	kV	kV	kV	kV	kV
Mica cambric ..	1	19·1	21·4	20·2	18·7	19·6	20·1
Flexible mica paper	2	23·0	28·8	30·5	27·0	26·8	27·9
Mica varnished cloth	3	31·5	34·7	35·2	35·0	33·4	34·9
Micafolium plate ..	4	27·5	30·7	33·8	28·8	30·6	29·7
Mica silk	5	24·4	26·5	31·6	25·2	28·0	25·9
Hard mica paper ..	6	33·0	31·5	40·3	35·8	36·6	33·6
Mica jap. paper ..	7	24·9	29·9	39·8	30·5	32·3	30·1
Flexible micanite ..	8	44·1	40·6	48·0	39·9	46·1	40·3
Hard micanite plate	9	36·0	33·8	36·0	29·5	36·0	31·7
Average		29·3	31·0	35·0	30·0	32·3	30·5

TABLE 18.

Material	Condition*	Thickness	B.D.V. at 30° C. tested in				B.D.V. at 100° C. tested in					
			Dry Air		Damp Air		Oil		Dry Air		Damp Air		Oil	
			B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength	B.D.V.	Elec. Strength
		in.	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil	kV	V/Mil
Varnished paper, No. 1 ..	D	0·063	31	490	—	—	50	790	23·5	370	—	—	23·5	370
	H	0·063	20	315	—	—	31	490	13·0	206	—	—	13·0	206
Ditto No. 2 ..	D	0·063	28	445	—	—	46	730	18·4	286	—		22·0	350
	H	0·063	20	315			27	430	14·0	223	—		12·0	190
	D	0·105					24·5	233					14·0	133
Varnished asbestos paper..	H	0·105		—	12·0	114	—	—			2·0	19·0		
	D	0·063			—		24·0	380				—	7·0	111
Red fibre	H	0·063	—	—	12·0	190	—	—	—	—	3·0	47·5		
	D	0·063	—	—	—		27·0	430	—	—			8·0	127
Grey fibre	H	0·063		—	3·0	47·5				—	Conducting			
Treated wood, No. 1 ..	N	0·250	—	—	—	—	44·0	176	—	—	—	—	22·5	90
Ditto No. 2 ..	N	0·198	—	—	—	—	61·0	310	—	—	—	—	15·0	226
Moulded composition, No. 1	D	0·188	15·0	80	—	—	27·5	146	10·0	53	—	—	6·0	32·0
	H	0·188	12·0	64	—	—	19·5	104	4·0	21	—	—	4·0	21·0

* D = dried; H = humidified; N = normal.

TABLE 19.

Average Breakdown Voltage for Miscellaneous Materials Calculated for a Thickness of $\frac{1}{16}$ inch.

Material	Average of all Tests in Air, B.D.V.		Average of all Tests in Oil, B.D.V.		Average of all Tests, E.D.V.	
	At 30° C.	At 100° C.	At 30° C.	At 100° C.	At 30° C.	At 100° C.
	kV	kV	kV	kV	kV	kV
Varnished paper, No. 1 ..	25·5	18·3	40·5	18·3	33·0	18·3
Ditto No. 2 ..	24·0	16·0	36·5	17·0	30·3	16·5
Varnished asbestos paper ..	7·3 (H)	1·2 (H)	15·0 (D)	8·4 (D)	11·2	4·8
Fibre	7·5 (H)	1·5 (H)	25·0 (D)	7·5 (D)	16·0	4·5
Treated wood, No. 1	—	—	13·0	6·5	13 (oil)	6·5 (oil)
Ditto No. 2	—	—	21·0	16·0	21 (oil)	16 (oil)
Moulded composition, No. 1..	5·0	2·6	9·0	2·0	7·0	2·3

D = dried; H = humidified.

with micarta, shellac and other gums give off certain acid liquids when heated above their melting point, and it was then observed that these distillates very seriously reduced the electric strength of micarta. When these mica insulations are employed in electrical machines they are usually wrapped layer upon layer and so confined that they cannot readily evaporate any volatile matter; consequently it is considered that tests in oil afford a truer indication of the behaviour of the materials in service than do tests in air. This opinion was confirmed by a number of tests on high-voltage stator bars insulated with various thicknesses of micafolium. The results of one such series of tests are shown in Fig. 23. These figures were obtained on a bar about 6 ft. long and insulated to a radial thickness of $\frac{1}{4}$ inch. As the percentage decrease in this case is considerably more than even that found in the oil tests on micafolium, it tends to show that in the case of very heavily insulated bars the volatile matter driven off from the shellac may very appreciably lower the breakdown voltage of the bars. Fortunately, as is the case with micarta, it is possible by suitable heat treatment during the manufacture of the coils to remove a large percentage of these volatile constituents, and in this way appreciably to increase the hot breakdown voltage of machines insulated with mica products.

Fibre.—Samples of both red and grey fibre were tested without being subjected to any varnish treatment.

Treated wood.—Wood can be successfully employed at high voltages in oil-immersed apparatus if it is thoroughly dried and impregnated with oil. Sample 1 was impregnated with a vegetable oil, whilst sample 2 was impregnated with a mineral oil.

Moulded compositions.—These are not usually obtained in such thin sheets as were required for these tests; investigations were confined to one class of moulded materials only, and a few results are shown later.

In Table 18 the usual results obtained at 30° C. and 100° C. are shown as for the other materials.

Table 19 shows the average results calculated as accurately as possible from the figures in Table 18. As the tests on several of these materials did not cover as complete a range as in the previous investigations, certain of the results are suffixed by a note signifying that they apply only to these particular conditions of test.

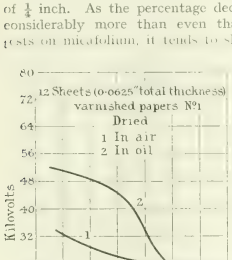

Fig. 24.

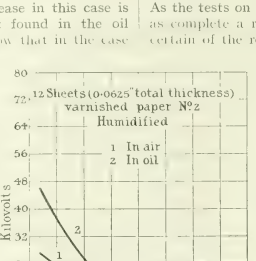

Fig. 25.

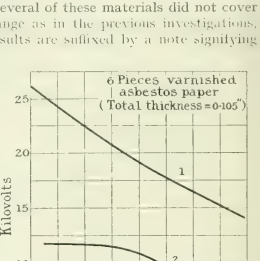

Fig. 26.

Figs. 24 to 26 inclusive show some of the temperature/voltage curves obtained during the tests on these miscellaneous materials. Figs. 24 and 25 are of particular interest in view of the fact that in these cases results were obtained up to a temperature of 140° C. They therefore give a little information in the hitherto unexplored region beyond 100° C.

(9) Miscellaneous Materials.

A few investigations were made on some other materials commonly employed in the insulation of electrical machinery. These included the following:—

Varnished paper.—Sample 1 was paper No. 2 of Section 4. Sheets were given several coats of a baking linseed-oil varnish so as to make the average thickness about 0·0053 inch. Sample 2 was paper No. 6 similarly treated to the same thickness.

Varnished asbestos paper.—Sheets of 0·010-inch asbestos paper were coated on both sides with an air-drying linseed-oil varnish until the average thickness was 0·0175 inch.

(10) Deductions.

In order that the large mass of information contained in Sections (4) to (9) may be more easily reviewed, the average figures for each class of material tested have been collected together in Table 20; and the percentage decrease in breakdown voltages for a rise of temperature from 30° C. to 100° C. has been calculated on the breakdown voltage at 30° C. It will be noticed that, although in a few cases of tests in air a small increase is obtained when breakdowns occur at 100° C., in the great majority of cases there is a very decided drop in the break-

down voltages, the values of which may be reduced to 50 per cent of those obtained at 30° C.

Table 20 shows that the mica products suffer the least loss of electric strength, whilst with micarta, temperature of the air, as has usually been done in the past.

This investigation has also shown that there is a very great need for systematic research work with a

TABLE 20.

Average Breakdown Voltage of $\frac{1}{16}$ inch Thickness of Various Insulating Materials.

Material	Average of Air Tests, B.D.V.			Average of Oil Tests, B.D.V.			Average of all Tests, B.D.V.		
	At 30° C.	At 100° C.	Increase or Decrease	At 30° C.	At 100° C.	Decrease	At 30° C.	At 130° C.	Decrease
	kV	kV	Per cent	kV	kV	Per cent	kV	kV	Per cent
Papers	12·0	13·7	+ 14	32·2	23·5	— 27	22·2	18·5	— 16·5
Micarta	27·9	7·7	— 7·5	28·8	11·8	— 61	26·3	10·8	— 59
Fullerboard	18·0	16·8	— 6·7	27	17·5	— 35	26·7	18·6	— 30
Varnished cloth	27·8	16·2	— 41·6	30·7	23·1	— 24·6	28·1	17·1	— 39
Mica products	29·3	31·0	+ 5·8	35	30	— 14·4	32·3	30·5	— 5·6
Varnished paper	24·8	17·2	— 30·6	38·5	17·7	— 54	31·7	17·4	— 45·5
Varnished asbestos paper	7·3 (H)	1·2 (H)	— 84	15·0 (D)	8·4 (D)	— 44	11·2	4·8	— 57
Fibre	7·5 (H)	1·5 (H)	— 80	25 (D)	7·5 (D)	— 70	16·0	4·5	— 72
Treated wood	—	—		17 (oil)	11·3 (oil)	— 33·5	17 (oil)	11·3 (oil)	— 33·5 (oil)
Moulded composition, No. 1	5·0	2·6	— 48	9·0	2·0	— 78	7·0	2·3	— 67

D = dried; H = humidified.

varnished asbestos paper, fibre and certain moulded compositions the decrease is the greatest.

(11) CONCLUSION.

This investigation has clearly shown that the electric strength of most of the solid insulating materials at present in use decreases with increase in temperature up to 100° C. As in modern machines hot-spot temperatures as high as or even higher than this may occur at periods of overloads, it is of the utmost importance that the electric strength of the insulating materials should be determined at 100° C. and not at the view to increasing still further our knowledge of the electrical characteristics of commercial insulating materials at temperatures likely to be attained in electrical machinery, and to developing new materials which will be more capable of withstanding these temperatures than the materials now employed.

The tests recorded in the paper were carried out in the Research Laboratories of the Metropolitan-Vickers Electrical Company. To this Company, and especially to Mr. A. P. M. Fleming, C.B.E., the author wishes to express his thanks for the privileges granted and for permission to publish some of the results obtained.

DISCUSSION ON

"THE 'CYC-ARC' PROCESS OF AUTOMATIC ELECTRIC WELDING."*

WESTERN CENTRE, AT BRISTOL, 5 DECEMBER, 1921.

Mr. W. Nairn: It is rather surprising to find a firm of welding specialists putting forward in one of the lantern slides a suggestion for the attachment of copper bonds to rails. In tramway work the tendency is to weld the rails and to do away with copper bonds entirely. Railway practice is of course rather different, but the open type of bond shown is not a practicable proposition, as bonds fixed in this manner would be promptly removed by thieves. For railway work a percentage of the fish-plates might be welded to the rails, say, in two out of three joints, and the third or expansion joint could be bonded by direct-welding a copper band in a concealed position.

Mr. H. R. Beasant: In connection with the suggested use of the process for rail bonding, I think that neither of the methods illustrated would form a satisfactory bond under the conditions of tramway practice. The first method, namely, to weld a brass stud to the rail and to use flat strip connections, would not give a permanent low-resistance connection, while the alternative method shown involves the use of solder connections, which experience has proved to be unreliable under these conditions. I suggest that a better way would be to weld the copper bond directly to the rail.

Professor A. Robertson: In view of some of the suggested applications of the system, I think that some caution should be exercised in the interpretation of the test results on mechanical strength. Too much should not be made of tests which show that the weld is stronger than the stud for a single application of the load. Many of the suggested applications involve alternation of stress; and to judge of the suitability of the system for loads of this character other tests are required. Many welds are certainly very poor when subjected to vibration or alternating stresses, and before attempting to use the system of welding for the attachment of the blade to a turbine rotor (to mention one important case) it would certainly pay to carry out tests under alternating stresses.

Mr. T. Hood: Will the authors say whether the welding tool can be used for welding metals of a low melting point, such as the brass metal joint pieces used to connect lead-covered wires on to brass fuse-container boxes on warships? I should also be glad to know if the apparatus could be used for drilling or melting holes through deck girders, stringers, etc., to allow cables to be threaded through. With regard to the authors' difficulties in using the apparatus with alternating current, I feel that the frequency of the circuit must have a considerable influence on the success or otherwise of this operation, and that if the experiments had been made with the Bristol supply at 93 periods much more satisfactory results might have been obtained.

* Paper by Messrs. L. J. Steele and H. Martin (see page 136).

Mr. A. J. Newman: In dealing with tube-to-tube welding I should be interested to know whether the process has been applied upon work necessitating the keeping of the tubes free from filling. One of the characteristics of the weld seems to lie in the fact that the tube itself gets filled. This limits its field of operation enormously. I suggest that possibly the idea of welding rail to rail and track to track may be impracticable. Has any development been made in welding cast iron by this process? The chief application which appeals to me is in connection with turbine blading, as, owing to the difficulties designers are labouring under at the present day in meeting market needs for cheaper plant (necessitating higher peripheral speeds), the welding of the blades to the discs seems to me to be an application worth careful consideration.

Mr. H. I. Rogers: As regards the manufacture of pantagraph and tube collectors, have the authors had any experience in welding tubes into sockets, as there would seem to be a considerable opening for the "Cyc-Arc" process in this direction? As regards the bonding of rails, I think that the particular methods shown by the authors would not be successful, although for bonding the rail to every fifth pole the apparatus appears to be very suitable and should lead to a great saving in time.

Mr. C. T. Allan: I suggest the application of the process to turbine blading, colliery work, and domestic utensils and appliances. The direct welding of pins to cross-arms for attaching to poles is also worth attention, as at present great difficulty is experienced through the rusting of the nuts to the pins.

Mr. A. C. MacWhirter: The authors have developed an entirely new branch of electric welding which I think will change many present manufacturing methods. Great advantages would be derived from the process if it could be applied to armature and rotor winding so as to eliminate soldering. In regard to welding materials of rectangular section, is there not a possibility of the arc missing parts in its travel from one end to the other?

Mr. W. F. Chamen: The process as demonstrated leaves a small mass of elevated brass around the stud which appears to be in the way when making face-to-face joints.

[Questions were also asked by **Professor D. Robertson** and **Messrs. F. L. Thomas, I. A. D. Pedler, J. J. C. Berkeley,** and **W. E. Hardy.**]

Messrs. L. J. Steele and **H. Martin** (*in reply*): We recognize that the methods of rail bonding described in the paper are by no means perfect from a practical standpoint, but they are submitted with the object of drawing sound practical suggestions from those with modern experience in this class of work. As a result, following the London meeting, we are

already considering an important modification of our proposals, in order to bring them into line with existing methods of bonding as used on most of the electrified railways in this country. The proposal now is to weld short brass or copper studs on to the rails, and to attach to them, by practically the same methods as are now used, the necessary copper bonds, which are fixed between the fish-plates and the rails, in order to avoid their being stolen, as experienced by Mr. Nairn. Our bonding proposals were not, in any case, put forward as being suitable for tramway work.

In reply to Mr. Beasant, the bonding questions have been almost fully replied to, but although his criticism of the proposal for sweated connections in bonding work is anticipated by us in the paper, one of the authors has, nevertheless, had experience upon colliery and light railway work in the Colonies, where such a cheap and rapid method of bonding could, it is believed, have been used with satisfaction.

In reply to Prof. Andrew Robertson, alternating-stress tests have been made of "Cyc-Arc" welds, with the result that such welds of brass to steel appear to give about the same results as those obtained with ordinary methods of arc welding. If the welds are annealed before testing, however, considerable improvement has been observed. From observations and rough tests already made on steel-to-steel welds, we anticipate that these will give remarkably satisfactory results under any form of alternating-stress test. Even the machine tools made by welding tips of high-speed steel to shanks of mild steel have withstood most remarkable tests, as stated in the paper. They have also been used for such work as reducing heavy couplings containing 6 bolt-holes, which subjected the tool to heavy jars when cutting across them. Before such welds are annealed, however, they are extremely brittle, and liable to break with the slightest jar. This can be readily understood.

We have subjected the process to a rather severe test in connection with light vehicle construction, by using it to weld screwed studs to the solid axles of a perambulator, the welded studs being passed up through the holes in the springs. This method of construction avoids the weakening of the axles which occurs when holes are drilled through at the very point where the maximum strength is required, viz. where the bolts pass up through the axles and springs in ordinary construction. In this connection, in spite of the severe shocks to which a small brass stud is subjected when used in the above-mentioned way on a perambulator which is heavily loaded and used on rough roads, none of the studs has broken anywhere near the weld, though two or three have broken in the thread, well away from the weld, owing to the fact that the brass stud at first used to substitute the former steel bolt was not sufficiently large. This difficulty has been overcome by using larger studs, with the result that solid axles are maintained, and an apparently successful constructional method for light vehicle work generally is thus evolved.

In reply to Mr. Hood, this method of welding is undoubtedly useful on board ship for many purposes besides the supporting of electric cables, but no attempts have been made to use it for welding lead to brass. The process certainly could be used for drilling or perforating ships' plating, though it has been designed specifically in order to avoid this. Involuntary perforation, particularly of thin plating, has, however, frequently been effected in experimental work. The advantage of high frequency for alternating-current welding by means of this process is recognized, but may be outweighed by certain disadvantages.

In reply to Mr. Newman, although it is preferred to weld tubes on to a solid object and if necessary drill or perforate after welding, "Cyc-Arc" tubular welds have been made on to objects already drilled or perforated so that the welded tubes are concentric with the existing holes.

With reference to the welding of cast iron, although "Cyc-Arc" welds can be made on to cast iron, such welding is not recommended, on account of the unsatisfactory nature of the cast iron itself from a welding standpoint. When such welds on to cast iron are subjected to tensile tests they do not break, but a small piece of cast iron is drawn out with the welded stud or tube. As a result of considerable experience in all classes of welding work in Portsmouth Dockyard during the past few years, we can state that the welding of cast iron is almost invariably unsatisfactory. Although it can be used for stopping leakages in, or holding together, castings in which the welded portion is subject to compressive stresses, we have no faith in its use for repairs in which the welded portion is likely to be subjected in practice to any appreciable tensile stress. An extremely satisfactory method for making "Cyc-Arc"-welded attachments to iron castings has, however, been proposed and tested, and particulars of this method are given in the paper. It is believed that there are considerable possibilities for development in the direction of the suggestions in question, viz. of casting-in mild steel angles, tees, or the like, by the method specified, and welding on to the cast-in mild steel sections, the necessary studs, tubes or other fittings.

The question of attaching turbine blading to rotors by means of our process has been previously considered, and we can see no difficulty in designing a plant suitable for this purpose. In this connection it is of interest to note that excellent welds of high mechanical strength can be made to cast steel, and also that rustless steel has been found to be readily weldable.

In reply to Mr. Rogers, we consider that there should be no difficulty whatever in welding tubes into suitably designed sockets by means of our process and apparatus. Such welds, on account of the reinforcement which invariably takes place, are extremely strong, and should compare favourably as regards mechanical strength with the constructional methods at present in use.

We are obliged for Mr. Allan's suggestions for various suitable applications for the process, such as for the direct welding of pins to cross-arms, for different kinds of work in collieries and mines, and for domestic utensil construction.

In reply to Mr. MacWhirter, we anticipate that we

shall be able, at an early date, to use the process for the welding of copper, in such work as rotor construction, and for armature connections. We have also used the process quite satisfactorily for welding rectangular pieces of manganese bronze about 1 inch long by $\frac{1}{2}$ inch wide, as well as for pieces of steel $\frac{1}{2}$ inch long by $\frac{1}{8}$ inch thick, but we do not at present know what the limits are in this direction.

In reply to Mr. Chamen, there are no apparent means of avoiding entirely the formation of fillets of metal around "Cyc-Arc" welds. These fillets can, however, be readily removed by machining, but it is preferable to retain them, where possible, on account of their reinforcing properties. This can, in many cases, be done by adopting suitable designs.

The replies to other questions raised are as follows :—

The suggestion that rails might be bonded by the welding of the studs used in attaching the fish-plates is considered to be quite feasible, provided that other difficulties in completing the bond can be overcome.

We agree that some difficulty exists in connecti with an alternating-current motor drive of the spec kinetic generator, but we consider that in the ca of a three-phase motor this should be satisfactori overcome by means of suitably designed slip-resi ances. A single-phase drive is to be avoided, possible.

The example shown in the lantern slide of the sh tubes welded on to a steel plate for radiator constru tion, illustrates one end plate only of a patent radiat which has been designed for, and is in use on, a Lond General motor omnibus. Between the two end plat are fitted large numbers of tubes, which are connect to the short welded tubes by means of special join

We believe that the welding of both copper a aluminium can be effected by means of our p cess, but we desire to obtain considerable improv ment, particularly in the mechanical strength of t welds, before recommending the apparatus comm cially for use in this direction.

North-Eastern Centre, at Newcastle, 12 December, 1921.

Mr. J. H. Holmes : I think the process described has a very large field of application and may be said to be in its infancy. The uses to which it has been put on board ship have the great advantage of dispensing with the driller, who is of a class of workmen often very difficult to deal with. Regarding what the authors say about tipping carbon steel with high-speed steel for tools, I should like to know whether they have been successful in using "Stellite" in this connection, as it may require no annealing. I should like to know what is the average voltage across the arc, and also whether the stud or the plate is made positive.

Major A. P. Pyne : Practically all forms of electric welding fall into one or other of two groups. Firstly, that in which two pieces of metal are held in contact with each other under pressure. The electric circuit is completed through the two pieces of metal, and the high resistance where the two portions of metal are in contact causes an increase of temperature which finally attains welding heat. Secondly, a building-up process in which additional metal is fed into a groove or on to the part to be built up. The fusing and welding of this metal is caused by the high temperature of the electric arc, whether this arc is struck by means of a carbon electrode and the metal is fed in independently, or whether the additional metal itself forms the electrode. Joining together two pieces of metal may be carried out in the case of the second process by placing them in contact with each other and building up a bridge of additional metal connecting the two parts together. It will readily be seen that the process described by the authors falls under the first category, which is in fact one of the oldest forms of electric welding. They, however, utilize it in an entirely new application, i.e. mainly for the attachment of studs to ships' bulkheads or for similar purposes. One of the great difficulties in electric welding is the fact that the efficiency of the weld is largely dependent on the operator, who must be not only skilful, but careful. A careless workman under the inducement of piecework can easily turn o a very bad weld which will yet be difficult of detectio A great deal has been said with regard to the relati merits of alternating current *versus* direct current welding. My experience, founded on a considera use of both types, is that in the hands of an exp who is used to alternating current, an a.c. weld quite as good as a d.c. weld, but it is advisable confine an inexperienced welder to direct current, considerable dissatisfaction may result. This appe to be largely due to the spluttering of the arc w alternating current, which prevents the welder fr seeing what he is doing as clearly as he would w direct current. An untidy weld results and, at the sa time, considerable burning away of the metal occ adjacent to the place at which the new metal is bu on. Thus in welding two plates together the jo itself may actually be stronger than the main bo of the plates and yet a considerable reduction in a may take place on each side of the weld. Th features, which must be guarded against in t more usual forms of electric welding, are refer to here in order to emphasize the fact that neither these difficulties arises in the process outlined by t authors ; in fact the human element, as far as the acti welding is concerned, has been almost entirely eli inated, and they are to be congratulated on perfecti a system having a great field of usefulness in warsh and liners. The shipyard electrical engineer is famil with the basketfuls of broken drills and taps periodica sent into store—a source of expense which this elect welding system eliminates, although at first sight would rather appear as if the outlay and complicatio involved would somewhat outweigh the saving effect It must be borne in mind that alternating current accompanied by much more danger to operators than direct current. This is amply proved by the numb of fatalities recorded due to alternating current extra low pressure during the past few years. No. su

fatalities have occurred with direct current at 250 volts and below. Alternating current, therefore, even at pressures as low as 60 volts, cannot be regarded as entirely safe on board ship.

Professor W. N. Haworth: Has a chemical analysis been made of the line of weld with a view to determining the extent to which interpenetration of the constituent metals has taken place? Doubtless at this point of junction there is interlacing, which may account for the great strength of the weld, and analysis may result in the discovery of new alloys possessing valuable properties. The difficulty of welding on to a galvanized surface, due to rapid surface oxidation of the metals, was overcome by the "Cyc-Arc" process, owing to the extreme rapidity of the operation. I can foresee motor-cars constructed of a framework lighter in design, and yet stronger by reason of the substitution of welded studs for ordinary bolts.

Mr. W. T. Dalton: When discussing the bonding of tram rail joints, the authors mentioned the placing of the bond behind the fish-plate. It is common practice to provide two 8-inch flexible pin bonds behind the fish-plates, but the objection to this is that, the bond holes being close to the fish-plate bolt holes, the web of the rail is weakened near the joint, and actual cases are known of the rail web fracturing at this position, the course of the fracture running from hole to hole. The usual alternative is to place 38-inch bonds over the fish-plates. While it must be admitted that a welded bond if placed behind the fish-plate would not possess the weakness referred to, it should be noted that the clearance between the inside face of the fish-plate and the web of the rail is little more than $\frac{1}{4}$ inch, and difficulty may be experienced in making a welded joint in such a small space, and the risk of having any obstruction which would prevent the pulling up of the fish-plate tight against the rail must be avoided. To secure the advantages of highest efficiency and least cost, it follows that bonds should be as short as possible, and, therefore, if the bonds are to be welded it may be found that the best plan is to keep clear of the fish-plates, and fix the bonds on the bottom flange, making them as short as possible, but providing sufficient flexibility to allow for any movement of the rail at the joint, thus preventing any strain being thrown on the bond.

Mr. J. T. Carr: When the difficulties of welding steel to steel have been overcome, I would suggest that a valuable application of the apparatus will be the welding of studs on boilers both old and new, for the fixing of valves and other gear. So far as the replacement of broken studs is concerned, the sending of several men on to the job and the expenditure of a good deal of time will be obviated. So far as rail bonding is concerned, I have no doubt that the process will be of very great value in the case of railway track work. In the case of tram rails, bonding is being replaced advantageously by arc-welding the fish-plates and joints into homogeneous units. It would appear that the value of the plant will be greater to a welding company than to a shipyard, since the latter, owing to the extraordinary efficiency of the invention, will be able to employ it for only a few weeks in the year.

Mr. J. A. Anderson: The satisfactory results obtained by the authors have rather upset my ideas regarding the electrical welding of metal to metal. I have previously been under the impression that this could not be done without developing oxides or blow-holes in the weld, unless precautions were first taken to ensure a neutral atmosphere in the arc. Some companies have done this by coating the metal rods with composition. I am of the opinion that the accurate timing of the arc and of the application of current after the stud comes into contact with the plate is responsible for the success of this process, and I do not think that the process can be described as either a filling process or a resistance process. It seems to me to be a combination of both.

Mr. P. F. Allan: I would suggest that the "Cyc-Arc" process might be used for the application of studs to apparatus such as joint boxes and feeder pillars. Another development I would suggest is that of designing the apparatus to take a long tube or bar through the centre of the chuck.

Mr. T. Carter: The kinetic generator is a striking application of the use of stored energy. I assume that a properly designed generator of this kind will take up the whole of the shock, and that there will be practically no evidence on the mains that a sudden peak has occurred. I should like to point out, with reference to what has already been said about the use of the term "welding," that if it is to be used to describe only joints made by hammering or pressure it ought not to be applied to electric arc processes of filling up, because, generally speaking, none of them comes within such a definition of welding. The authors' process appears to have more than one characteristic so far as its essential nature is concerned; it is an arc process to begin with, and there may then be a pressure stage, and finally if, as I gather, the current is kept on during the last stage, there may even be a certain amount of butt-resistance action. I hope the authors will comment on this point, and tell us exactly what the nature of the process is in this respect. They state that the cost of welds made by the "Cyc-Arc" process is about one-quarter the cost of similar welds made in the ordinary way. It is important to know whether this estimate includes an amount for the first cost of the apparatus and its maintenance, or whether it refers only to the actual cost of making the weld. I understand that there is as yet no portable apparatus for making steel-to-steel welds, and I should like to know what prospect there is of appliances for such welds being reduced to a portable form. One of the most interesting points about the process is that it has reached its present advanced stage although it is as yet impossible to account for much of what happens in connection with it, and although it is difficult to understand why the results should in many instances be as good as they are.

[Questions were also asked by **Messrs. R. P. Wallis, W. C. Lambourn, O. Josephs, H. J. Fisher, J. A. Henderson, R. W. Clark, W. T. Maccall,** and **G. C. Mallinson.**]

Messrs. L. J. Steele and **H. Martin** (*in reply*): With regard to Mr. Holmes's remarks, the "Cyc-Arc"

process has not yet been used for welding "Stellite," but it is intended to try this at an early date and no great difficulty is anticipated in satisfactorily accomplishing it. The pressure across the arc when welding brass to steel may be taken as being from 20 to 24 volts. In welding steel to steel, however, the pressure across the arc is considerably higher, and may even exceed 30 volts. Our present practice is almost invariably to make the stud positive and the plate negative.

We must certainly ask Major Pyne to consider our method of welding apart from either of the forms mentioned as falling into one or other of two groups. We feel sure that if he had been able to see the apparatus in operation, he would certainly not have associated our process in any way with resistance welding. The process, as its name indicates, is essentially an arc welding process, although, as stated elsewhere, it differs radically from all other such processes. We are interested in, and agree with, Major Pyne's comparison of alternating-current with direct-current welding, but at the present time we have no intention of recommending our process to be operated from an alternating-current supply on board ship.

In reply to Prof. Haworth, chemical analyses have not yet, as far as we are aware, been made of the material at the line of a "Cyc-Arc" weld, but we appreciate the importance of this suggestion, and hope to have information available at an early date as the result of following it up.

We are obliged for Mr. Dalton's helpful remarks and suggestions in connection with rail bonding. These have, however, been discussed fairly fully at both London and Bristol.

In reply to Mr. Carr, we agree that the attachment of boiler mountings will form a valuable field of application for steel stud welding by our process, but we feel compelled to state that we also think brass or bronze studs welded by the same process will be ultimately accepted for similar work.

We are pleased to note that Mr. Anderson does not think that our process should be described as either a filling or resistance process. We cannot agree, however, that it is a combination of both; on the contrary, we feel sure that it should be associated with neither, for the reasons that the molten metal of the stud and plate, which is formed during the arcing period, is displaced upon the completion of the weld, and that any slight amount of heating produced at the weld upon its completion, owing to the current supply not being cut off instantaneously, is negligible.

We are obliged for Mr. Allan's suggestions for useful applications of the process in connection with joint box and feeder-pillar work, and would inform him that patent applications have actually been made for apparatus designed to take long bars or rods in accordance with one of his suggestions.

In reply to Mr. Carter, we think that sufficient has already been said in regard to the essential nature of the "Cyc-Arc" process. Attention is drawn to the fact that it is not claimed that the cost of welds made by the process is about one-quarter the cost of similar welds made in the ordinary way, but rather that the cost of work done by the process is about one-quarter that of the equivalent work necessary (e.g. drilling, tapping, etc.) by present methods. In making these cost comparisons full allowance has been made for the capital and maintenance costs of the apparatus. There is, at present, no prospect of constructing as light and portable an apparatus for steel-to-steel welding as for brass stud welding, though an apparatus of a semi-portable type, suitable for ship and locomotive work, etc., will shortly be available.

Replies to other questions raised during the discussion at Newcastle are as follows:—

Jigs have not only been used already, but will almost invariably be necessary for repetition work carried out by means of the process, and particularly for work on large flat surfaces and circular plates.

No experiments have yet been made on the welding of cable connections.

It is not anticipated that an ordinary mechanical chuck will be suitable for steel stud welding, mainly on account of the necessity for good electrical contact in passing the relatively heavy currents required. We consider, however, that only a slight modification of the ordinary mechanical chuck is necessary to make it suitable to meet our requirements.

We have not reached the stage of development at which we can attempt to weld boiler tubes, and the use of the process for such applications as locomotive fire-box construction and armature and commutator work, depends upon the result of experiments now proceeding in the welding of copper.

The apparatus is not designed to carry out seam welding.

Satisfactory welding of aluminium has not yet been accomplished, but arrangements have been made to experiment in this direction at an early date.

The first 8 tests, referred to in the paper as having been made by Messrs. Avery, were all taken on plain unscrewed brass rod welded to mild steel rod.

There is no difficulty whatever in attaching electric cable clips and other fittings to ordinary ships' plates. This is the application for which the Type A apparatus was designed, and for which it is in practically constant use.

Scottish Centre, at Glasgow, 13 December, 1921.

Mr. A. E. Frankling: I should like to offer a few remarks on the "Cyc-Arc" welder from the point of view of one who is directly concerned with and greatly interested in electrical installations in ships. It will have been apparent to those who have witnessed the working demonstration this evening, that the operation of stud welding is very simple, and it is due to this simplicity that there is a fear of the apparatus being put in the hands of an operator who, by reason of lack of initiative, disinterestedness or personal antipathy towards it owing to its labour-saving possibilities, would not give it a fair chance. I hope that discrimination will be exercised

in the selection of operators, and that they will be given the requisite instructions and preliminary training before being allowed to undertake work on a ship: also that we shall be enlightened as to the attitude which it is anticipated the trade unions will adopt towards this labour-saving apparatus. If it is insisted that the men displaced by the adoption of this apparatus are to operate it and, further, that the numbers displaced are to be found employment in connection with its application, I am afraid that the apparatus will not be given the chance that it deserves. I consider it most important that each operator should be supplied with a simple but reliable apparatus for testing his work as he proceeds, and I think that a spring-loaded **L**-shaped bar of which the toe is provided with a coned recess for engaging with the two halves of a split-coned nut that can be placed over a few threads of stud, would be satisfactory for the purpose, as the stud would be pulled in the direction of its length by pressing the bar down. It is well known that considerable use is made of perforated steel plating for carrying electric cables along bulkheads and over obstructions, etc., thus reducing the number of holes in them to a minimum. About 20 tons of plating, costing on an average £50 per ton, would be used on a large vessel provided with an extensive electrical installation, and it is estimated that at least one-half of this weight and cost would be saved by welding studs direct to bulkheads, etc. On page 139 of the paper, the authors refer to a ball-ended stud as being the most suitable for welding, but it has been my experience that cone-ended studs are equally suitable; moreover, owing to the cone end being of the same diameter as the threads, there would be a saving in cost, which is a point to be not lightly set aside, in view of the considerable quantity of studs that are required, also there is the advantage of being able more accurately to centre this stud in the position marked off for it. I think that the apparatus would be improved if a double-pole contactor were substituted for the existing single-pole one shown in Figs. 4 and 5, as the generator would then be earthed only during such time as a weld was in progress. A mishap in the early days of the experiments was attributed to the lack of this precaution. The authors have been very modest in their claims as regards the advantages possessed by this stud-welding process when compared with the method at present in use. The following are a few of the more important savings in cost that will be affected:—(*a*) Surveying the reverse sides of bulkheads, etc., prior to deciding the positions of the cable runs in order to determine whether "through" holes may be drilled without detriment to apparatus fitted on the other side. (*b*) Rigging staging in order to permit insertion of studs from the reverse side of bulkheads, etc. It frequently happens that a day will be taken to rig a stage that may be required for only a few minutes. (*c*) Drills, taps and the time taken in proceeding to the grindstone to sharpen the former. (*d*) Punching out broken taps from the holes, plugging the latter, and drilling and tapping fresh holes. (*e*) Shifting coal in bunkers so that a man may enter to insert studs in bulkheads. (*f*) Time taken in draining pneumatic drilling-machine supply-pipes in frosty weather. I have mentioned some of the principal savings and advantages that would accrue from the adoption of the "Cyc-Arc" process, and will now refer to a matter which will require a certain amount of attention. When perforated plating is fitted, usually a space of about 1 inch is left between it and the bulkhead, etc., with the result that damage to cables, by reason of their having been drilled into from the reverse side of the bulkhead, is comparatively negligible. It is obvious that when cables are secured direct to bulkheads, etc.—as will be the case when studs are welded thereto—the risk of the cables being drilled into from the reverse side of the bulkhead will be considerably increased unless precautions are taken to call the attention of all concerned to the fact that electric cables are in certain positions. I suggest that before the cables are placed in position, the reverse sides of bulkheads should be painted with two broad white bands having cross-hatching between them in order to denote the positions and widths of cable runs on the other side, and that the words "Electric Cables Other Side" should be stencilled between the bands. I think that the adoption of this, or some equally simple precaution, would reduce to a minimum the risk of damage to the cables.

Mr. W. B. Hird: The fixing of studs to bulkheads appears to be the chief use to which this welding process has been put, but I am glad to see that it is intended to develop its use in other directions. From the fact that the heating is so local and that the whole operation is carried out in a very short space of time, there would appear to be some hope of the process being applied to welding copper to copper so that it might conceivably become a very useful method of making joints between copper conductors in electrical work. It might even be anticipated that an armature winder would use a "Cyc-Arc" welder instead of a soldering bolt.

Mr. D. M. Buist (*communicated*): I should like to know if the authors recommend special ball-headed studs for all welding work, and if ordinary round or snap-headed iron studs could be welded with equally good results. Not only would the latter be cheaper, but they would also present a shoulder to the article which it is intended to support. The authors do not state the extent of the upset of the weld, consequently I should like to know how they overcome this inconvenience, however small it may be, in welding studs to such work as flanges of casings, pipes and engine cylinders. Perhaps they avoid the upset by providing sufficient clearance in the hole. In Fig. 11 the holes in the cover are 7/16 inch, but the size of the stud is not given. Referring to the diagrams of connections, I note that in Figs. 4 and 5 the plate constitutes the positive electrode, whereas in Figs. 7, 9 and 10 it is made the negative. Since approximately 70 per cent of the total heat of a direct-current arc is said to be generated at the positive crater, it seems advisable that the plate, or in general the electrode which possesses the greater mass, should always be made positive, as then there would be a tendency to equalize the heat in each electrode, thereby assisting in giving a better weld by preventing the stud from fusing long before the plate. As regards polarity, it would have been useful in studying the question of penetrating and local heating if the authors

had stated the polarities in the specimen welds which were examined at Messrs. Vickers. In summarizing the results of these examinations, the authors attribute the undoubted strength of the welds to (1) penetration, (2) extreme local heating, and (3) absence of oxidation, but I think that the strength of a weld depends almost entirely upon the presence or absence of flaws, and that the micro-structure of the weld itself is of minor importance in this respect. This means that the predominating factor in successful welding, especially by arc, is skill in operation, and, since the human element is practically eliminated in the authors' process, the conclusion is that the success of this process is chiefly due to the fact that it is automatic in providing the correct length and duration of the arc. Unlike the Thomson or resistance method of welding, oxidation is an inherent defect of arc welding, owing to the greater possibility of the admission of air into the weld. The "Cyc-Arc" process employs the minimum length of arc, with the consequent minimum disturbance, especially by draught, and the authors are therefore to a certain extent justified in claiming absence of oxidation as a merit of their system. With regard to penetration and local heating, I think these advantages can be claimed for metal arc welding in general, but in any case they, especially local heating, affect the strength of the metal immediately outside the weld more than that of the weld itself. For this reason, I was glad to see that the paper did not contain any photographs purporting to show the strength of welds as being so great that the metal outside breaks first. I should like to know if the specimen welds submitted to Messrs. Vickers were made on new metals, and I think that chemical analyses of the drillings of these welds should have been made. It may be generally accepted that materials with a negligible carbon content will weld with few or no blow-holes, while the presence of manganese seems to improve the weld. These points are substantiated by Messrs. Vickers' reports. I fail to see why the authors should at first have attributed the so-called "cavitation effect" either to premature chilling or to the imprisonment of a bubble of nitrogen, which impurity is very rare in the metals usually welded, as I think the cavity was merely a blow-hole formed by carbon monoxide, due to the switching off of the current before closing the weld, thus allowing the air to rush in. It was only to be expected that oxidation was visible in holes open to the air. In Section (7) the authors state that they have made satisfactory welds under water, but I should be glad to hear if they examined these for flaws and oxidation.

Messrs. H. J. Steele and **H. Martin** (*in reply*): With reference to Mr. Frankling's proposal for a simple but reliable apparatus for testing stud welds as they are made, an almost identical arrangement has recently been provided at Portsmouth Dockyard for the same purpose. We do not, however, consider such a testing device to be necessary, for, as stated elsewhere, any operator of reasonable skill and intelligence can pick out doubtful welds by inspection and observation.

The ball-headed studs recommended for use by the authors simply give a larger margin of safety, and are recommended more particularly for use in awkward positions, or upon badly pitted or oxidized plates. T concealed stud referred to by Mr. Frankling c undoubtedly be quite readily welded by our proce and, as a matter of fact, is much more frequent used than the ball-headed stud. It is not agreed th a double-pole contactor is necessary for use with t apparatus, and its use would appear to involve t addition of unnecessary weight. No trouble whatev has been experienced with the present commercial ty of apparatus fitted with a single-pole contactor.

In reply to Mr. Hird, it is anticipated that the proce will be found suitable for a number of applications connection with the welding of copper.

In reply to Mr. Buist, we have already remarked upo the use of the special ball-headed studs, which a certainly not necessary for all welding work. Bo round- and snap-headed studs or screws can be, a have been, welded by the authors' process, and is agreed that in some cases they would adva tageously present a shoulder to the article whi it is intended to support. It is pointed out, howeve that iron studs cannot be welded with the prese portable "Cyc-Arc" welding tool. The extent of t upset of the weld with this process is an importa matter which we are glad has been raised in the di cussion. In the case of welding brass studs this ups is to some extent under control, i.e. it can be reduc to a minimum by generating excessive heat at t weld for rather more than the normal time perio The resulting weld, however, is not so mechanical strong as a weld made with the correct current densi and time period, which weld, upon completion, has appreciable upset of metal surrounding it at the jun ture of the stud with the plate. This upset, thou not of absolutely regular section, is, as would expected, thicker near the stud, and tapers off nothing at a certain distance from it. The amoun of upset surrounding an average ½-inch diamet "Cyc-Arc" weld may be taken as being 1/32 in maximum depth, and about 5/8 inch outside diamete the figures for other sizes of welds being proportionat This will be found to be a comparatively sma amount, and one which can easily be cleared by slight countersinking the underside of the fitting which to be attached to the plate. Alternatively, in son cases, suitable countersunk washers may be interpose between the fitting and the plate. In certain speci cases, however, this upset may readily be machine off in a few seconds by means of a special hollow cutte though, as it undoubtedly reinforces the weld as fa as mechanical strength is concerned, it is general preferred to leave it. The corresponding upset wi steel stud welding is somewhat greater, as would expected with a metal which does not readily volat lize, but if the upset in question is reasonably unifor in shape we think there will not be any great difficult in providing for it in actual practice. Though w ourselves formerly theorized along the lines suggeste by Mr. Buist in respect to the advisability of makir the plate the positive, we can now state quite definite that the opposite polarity almost invariably gives t best results. The majority of the welds submitted t

Messrs. Vickers were probably made with what we take Mr. Buist to refer to as new metals. A number of under-water welds have been made by the "Cyc-Arc" process, many of them being of high mechanical strength. Our general impression is, however, that greater accuracy is necessary in setting both time and current for such welds, and that there is a greater tendency for the formation of flaws. No particular tendency towards oxidation has so far been observed. With reference to Mr. Buist's remarks on the so-called "cavitation effects," we consider it extremely unlikely that carbon monoxide gas could be so formed during the period of a "Cyc-Arc" weld (particularly in the case of such a weld between brass and steel) as to account for the large cavities to which reference is made in the paper, and of which lantern slides were shown. In addition, we are convinced that, apart from the question of the filling of these cavities, they were primarily brought about by the rapid chilling which took place when the current was cut off before completing the weld, thus causing the chilled peripheries of both stud end and the plate to meet first, upon the return of the stud to the plate, and preventing complete closing up at the weld.

South Midland Centre, at Birmingham, 11 January, 1922.

Professor W. Cramp: It is not clear to me why the weld should be free from oxidation, unless it be due to the intensely localized heating, which is one great feature of the process. I think, however, that I can throw light upon the reason for the strength of the joint. A number of micro-photographs from samples submitted by Mr. Steele were made at the Birmingham University, and these show, even more clearly than those in the paper, the character of the joint. It is clear that, regardless of the direction of the current, the steel penetrates the brass in the form of long isthmuses, forming irregular dovetails. I have not found any evidence of the penetration of the steel by the brass such as the authors state that they have found. This dovetailing gives a mechanical joint of great strength, and at the point of contact, for a depth of about 1/50 inch, the character of both metals is changed. In the brass the zinc appears to have partly disappeared, leaving a mixture rich in copper, and in the steel some of the carbon has disappeared, leaving the metal rich in ferrite. This means that at the joint the two metals are not only dovetailed, but are of a tougher character than the original samples. On page 155 the statement regarding Fig. 14 is not clear, since from the connections shown it appears that, though only one armature winding is connected to the series coil, both supply current to the welder, so that it is not true to say that only one winding strikes the arc. The figures of tests on the direct-current motor-generator do not include any efficiency figures; these would be interesting. With regard to the permanence of the joint, it occurs to me that, since the union is so largely mechanical, it may possibly happen that the line of junction along the dovetails is not moisture-proof. In that case, if sea-water gets in, even to a very small extent, electrolytic action and corrosion will result. I should like to know whether the authors have made tests in this direction; also whether they have tested the joint for electrical resistance.

Dr. C. C. Garrard: I am particularly interested in the method of welding which the authors have demonstrated to-night, because some 18 years ago I worked upon a somewhat similar problem. This concerned the welding of steel turbine blades on to the discs or wheels of steam turbines. The method was a resistance one, i.e. the blade was held against the periphery of the wheel, and the heat generated at the contact caused softening. The welding machine, which was specially constructed for the work, then pressed up the blade a certain distance, thus causing the weld to take place. This movement of the machine actuated the cut-off switch which interrupted the current and prevented overheating. The welds thus obtained were quite successful.

Mr. G. M. Harvey: Throughout the paper, the welding of comparatively short studs to other surfaces has been dealt with. Is it possible, by modifying the form of the stud-holder, to use this process for welding the ends of much longer bars in a similar manner? The process described in connection with the bonding of rails seems scarcely an improvement upon the present method, as it does not obviate the two unwelded face-to-face joints. In the ordinary case these are between the ends of the bonding bar or strip and the rail, while in the "Cyc-Arc" process the bond is either bolted to welded studs or soldered into welded sockets. Could not the two ends of the bonding bar itself be welded direct to the rails without the intervention of any unwelded joints? Obviously this could not be effected if the rails were electrically connected, but this could easily be overcome by removing the fish-plates during welding in the case of "live" rails, while in the case of earthed return rails it would be necessary, in addition, to knock out the keys and place a strip of micanite around the rail at each chair.

Mr. A. H. W. Busby: The time interval between the pressing of the push buttons controlling the timing gear and the striking of the arc is rather long. Could not a means be devised to reduce this interval, as it is much longer than the time taken for the actual weld?

Messrs. L. J. Steele and **H. Martin** (*in reply*): In reply to Prof. Cramp, we certainly think that there are reasons why "Cyc-Arc" welds should be free from oxidation, apart from the feature of the intensely localized heating. Surely other features, such as the extremely short length of arc upon striking, as well as the very short period for which it is maintained, combined with the fact that both the arc length and time period are uniformly and accurately controlled, tend to keep oxidation at the weld down to a minimum. Even assuming that slight oxidation of the molten metal takes place, attention is drawn to the fact that any such slightly oxidized metal (as stated in our reply to the discussion at the Institution, is presumably

forced out between the stud and plate upon the completion of each weld. There may, however, be other reasons which at present are unknown to us.

With reference to the question of interpenetration of the metals welded, while it is agreed that the steel which is connected to the negative pole of the supply circuit, and which has a considerably higher melting point, may penetrate into the brass to a greater extent than the brass will penetrate into the steel, we nevertheless feel sure that there must be some interpenetration, though with the normal "Cyc-Arc" method of welding these metals together the amount of penetration of the copper constituent into the steel is probably relatively slight.

In further reply to Prof. Cramp, although we agree that the statement respecting Fig. 14 is not strictly accurate, we thought it would be understood that, owing to the inductive effect of the series winding in one armature circuit, the other armature necessarily supplies by far the greater portion of the first rush of current when the arc is struck. We did not intend to convey that no current whatever would be taken from the other armature at this stage of the welding process. We do not consider that the union between the metals at the weld is of such a nature that there is any possibility of the metal at the line of juncture not being moisture-proof. Tests have been made with sea-water upon welds, both complete and in section, but we have not discovered, with the means at our disposal, any electrolytic action or corrosion at the welded faces. Electrical conductivity tests have shown that the welds appear to be in all respects equivalent to the solid metal.

We are interested to learn of Dr. Garrard's experiments on the resistance welding of turbine blading and we feel sure that our process can be used for similar purposes.

In reply to Mr. Harvey, there is no difficulty whatever in the welding of long rods or tubes by our process, with a fixed type of welding tool. It is only necessary to provide simple mechanical accessories, in the shape of supports and guides for the rods or tubes in question. Not only have special designs been evolved for dealing with this kind of work, but patent protection has been obtained for some of our proposals in this direction.

The great advantage claimed in using our process for bonding purposes is that an ideal electrical connection is made at the weld between a highly conducting and non-rusting metal, such as brass or copper, and the rail. After connecting in this manner to the rail there appears to be no difficulty in making, by mechanical means, good electrical connection to the brass or copper studs welded to the rails, whereas we do consider that electrical connection by mechanical means between the ordinary copper bonds and the steel rails is not invariably satisfactory. We agree, however, that there is a possibility of directly welding the bonds themselves to the rails by the process, providing that there is no objection to the removal of fish-plates, etc., during welding, as suggested by Mr. Harvey.

In reply to Mr. Busby, a detailed explanation of the reason for the time interval between the pressing of the push button controlling the apparatus and the striking of the arc is given in the paper, where it is also stated that in cases of the use of the apparatus continuously and rapidly on one particular class of work, which use requires a uniform time period, a much cheaper timing and control apparatus can be provided, so designed that instead of each operation of the timing apparatus occupying a 7-second period, the arc strikes practically instantaneously when the push button is pressed. We would point out, however, that the time period to which Mr. Busby draws attention is practically negligible when using the portable-tool type of apparatus upon ship and other work, in which relatively long periods elapse in moving from position to position, etc.

HIGH-SPEED WIRELESS TELEGRAPHY.

By Lieut.-Col. A. G. T. Cusins, C.M.G., Royal Corps of Signals.

(*Paper received 15th November, 1921, and read before the* Wireless Section, *4th January*, 1922.)

Summary.

This paper consists in the main of a record of experimental progress directed towards the mechanicalization of wireless telegraphy in as simple and portable a form as possible.

One of the great difficulties in a modern war on a large scale was shown to be that of providing at short notice the trained personnel necessary for the manipulation of scientific and highly technical apparatus. Simplicity in handling such apparatus is therefore a matter of great importance.

Experimental work has now arrived at a point at which it has been shown by practical experience that apparatus can be produced which, in the hands of operators of average ability, enables wireless telegraphy to be carried on by mechanical operations both in transmission and in reception, either by itself or in continuation of a line system; and this at all speeds up to the maximum of Wheatstone apparatus.

In order that wireless telegraphy may become a real success in the present and be capable of considerably expanded utility in the future, it is becoming obvious that certain facts will have to be faced. The recent International Conference in Paris disclosed the disquieting fact that the ether is already in danger of being overcrowded.

Even taking into account the refinement which has been attained in selectivity, that is to say in reducing the percentage difference in frequency at which two simultaneous messages can be received conveniently, and allowing full credit to the progress made in directive working both in transmission and in reception, even then the gamut of frequency over which operation is possible is very limited, and between the upper and lower limits, say from 6 000 000 to 6 000, or in wavelengths from 50 to 50 000 metres, choice is further limited by the interdependence between the three factors, power, frequency and distance. As the mutual interference between very large stations becomes more marked, it is possible that they will tend to be limited to operations over ocean tracts where distance is the deciding factor.

Over shorter distances it is suggested that the practice will arise of installing medium-power stations with a more limited area of operation and relaying traffic from one to another. Such a system, employing a geographical method of distribution of wave-lengths so as to minimize interference, in place of the existing national scramble, should prove itself very elastic and capable of expansion. In order to make full use of such a system, however, it is imperative that it be used economically by combining selectivity of reception and speed of operation; and in speed of operation must be included facility of relaying from and to adjoining stages of either wired or wireless communication.

It is such a system that is here brought forward. In its actual form it is necessarily of a "semi-portable" type, that is, that the work of installation, dismantling and transport is such as could be undertaken by the Signal staff of one of the larger Army formations, a corps for instance. In the less cramped circumstances of commercial working in peace time there seems to be no reason why it should not be brought to a very high degree of refinement and efficiency.

As the dependence of the Army on wireless working began to increase towards the end of hostilities, when trench warfare—and with it a practically permanent wired system of communication—dissolved into the swaying war of movement of 1918, it is not to be wondered at that the limitations of wireless telegraphy as then known began to be felt.

There had long been certain problems of universal interest, of which the most important were:—

(1) At what interval, in terms of wave-length and distance, can reception be carried on in the neighbourhood of simultaneous transmission? In war this means, can a small signal unit work duplex wireless and at the same time feed its men satisfactorily? And also, how many wireless sets can be put in per square mile of battle area?

(2) Can anything be done to limit interference caused by atmospherics?

And later the two following arose:—

(3) Can wireless be made a ready alternative to wire telegraphy? In other words, can the same terminal instruments and operators be used for both?

(4) Is there any prospect of being able to handle heavy traffic at more than hand speed?

The last, if we consider, includes all the rest.

The problem can be stated as follows: Can we make the use of wireless such that it can be operated with ordinary terminal instruments, whether hand or automatic, and be capable of translation to or from either wire or wireless, with such selectivity as to eliminate the human element, be reasonably free from interference by atmospherics, and at the same time call for only such power of transmission as can be provided for field use?

It is because this problem is of such universal interest that it has been thought that the stage to which it has been brought by the Army should be made generally known.

It had been made obvious, during some experiments for a purely military purpose, that the valve relay invented by L. B. Turner and fully described in a paper entitled "The Oscillatory Valve Relay, a thermionic trigger device" * provided the key to the satisfactory automatic recording of wireless signals.

* *Journal I.E.E.*, 1919, vol. 57, Supplement, p. 5[illegible]

In a very clear preliminary report on the possibility of applying the valve relay to the reception of high speed wireless signals Captain Turner laid stress on several features which a really satisfactory automatic receiving apparatus should possess. It may be a satisfaction to him to know that, though we have not been able to solve all the problems he then laid down, at any rate he exhausted the list and very effectively braved the passage. The main features of the valve relay are :—

(1) It is extremely selective.

(2) It shows a marked preference, as much as 50 to 1, for "undamped" as against "damped" waves, and is thus to a certain extent a guard against atmospherics and spark working.

(3) It provides a means whereby a local current can be varied instantaneously to a considerable extent by the effect of a comparatively weak incoming signal. It is, in fact, a practicable relay.

Regarding the problem of reducing local interference, attention was naturally directed to the loop as being possibly the most satisfactory receiving aerial for all purposes to which it is applicable. But the use of the loop, and the desirability at the same time of reducing the power required for transmission, obviously called for redoubled effort on the problem of amplification.

Here again it was realized that, however selective the relay might be, it would be an additional advantage if the incoming signal could be supplied to it through a highly selective high-frequency amplifier capable of giving definite prominence to signals on the desired wave-lengths.

In order therefore to arrive at a solution of the whole problem, experiments were carried on to develop the uses of the valve relay, to investigate the question of loop reception, and to evolve a really satisfactory tuned high-frequency amplifier.

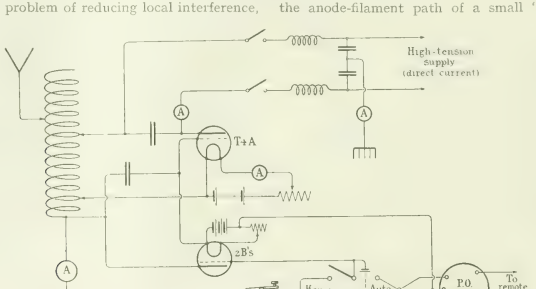

FIG. 1.—Continuous-wave set for field use, with high-speed attachment.

TRANSMISSION.

In order to be able to transmit signals at high speed in the field, it is obvious that complicated mechanisms are out of the question. We must be able to use the Wheatstone, and its application must be as direct and simple as possible.

In this connection it may be mentioned that we are now able to do this on sets up to 6 kW. For this we are indebted to Dr. Brydon, Captain Johnson and Captain Whittaker Swinton, the officers who had technical charge of the development of the latest military transmitter, and on a 6-kW set we now key with an ordinary single-current key straight into the circuit without any intermediate mechanical device.

For remote control, whether at hand or high speed, the key is replaced by a Creed relay. The action is practically sparkless, in spite of the fact that the high tension voltage reaches 9 000 volts.

However, for the small sets, of about 2 kW, now working between Aldershot and Cologne, trial was made of a device which had already been used with success for long-distance telephony. This consists of utilizing the anode-filament path of a small "control" valve as the grid leak of the main generating valve. By operating on the grid-filament circuit of the control valve, the resistance of its anode-filament path may be varied enormously, and the oscillations of the main generating valve be controlled instantaneously over their full amplitude. So delicate is this method of control that it is easily possible, using an ordinary Post Office Wheatstone transmitter, unaltered, to close the grid-filament circuit of the control valve when a signal is required to pass, and to apply the requisite negative tension to the grid and so check the oscillations of the main generating valve during the spacing period.

This action is to all intents and purposes instantaneous; for even if 50 oscillations were required to build up the oscillation of the main valve to full amplitude, at a wave-length of 1 500 m a period of only 1/40 000 of a second would be involved.

A diagram of this circuit is shown in Fig. 1. In this, the actual Wheatstone instrument is shown as being at a distance from the transmitter, the signals being relayed to the latter through a Post Office relay

This, of course, allows of the sending of a message from an office at any desired distance from the wireless transmitting station, passing the message from wire to wireless without any intermediate re-transmission. Such an arrangement enables an operator to have his receiver and his sending instruments, key or Wheatstone, in the same office and to send his replies through a transmitting station installed at a distance. The system goes by the name of "remote control," and opens up possibilities of duplex working.

The circuit shown can be utilized with any form of direct-current high-tension supply to the main generating valve.

The actual set at Aldershot which is now working to Cologne, operates on an aerial consisting of two 300-ft. wires between 70-ft. masts. Earth resistance, 6 ohms; aerial current, 10 to 12 amperes. This power is found to be sufficient for regular working under fair conditions. It has actually been the case that an important message, which had repeatedly failed to get through by hand transmission and aural reception, owing to atmospheric disturbance, was successfully handled at high speed with automatic reception.

A somewhat larger factor of safety will, however, so far as can be foreseen, have to be allowed in order to meet the varied conditions of Army working.

It may not be generally known that for some time the Post Office have been conducting trials of this somewhat under-powered set, and traffic between London and Germany has been carried on a single wire and earth between the Central Telegraph Office, London, and Aldershot, then from Aldershot to Cologne by military wireless, and from Cologne military wireless station to the German Post Office by wire. Through transmission has also been carried on with a certain amount of steady success, using Wheatstone transmission and Creed printer reception, the working speed being 100 words a minute.

Reception.

(1) *Loop reception.*—As this method is so well established, it need only be remarked that it provides, by its directional properties, a ready means of eliminating many undesired signals. For small and medium-size stations, where room is a consideration, it allows of the transmitter being placed at such a point as will cause a minimum of interference while still maintaining maximum efficiency on the line of direction of reception; and recent experiments have resulted in the reduction of such interference to a most remarkable degree.

It may be mentioned that, using a loop arrangement devised by Captain Hughes, the signals emitted by the 5-kW station of the Air Force at Kidbrooke have been reduced to complete inaudibility, the distance from Woolwich Common being about 2 miles.

(2) *High-frequency amplification.*—It is well known that there is a point below which an unaided signal fails to operate a detector, and to cause a detector valve to "rectify" it is necessary to bring up the intensity of the signal by means of high-frequency amplification. Unfortunately, it had been found very difficult to apply any principle of tuning to high-frequency amplifiers, owing to the instability, or tendency to break into self-oscillation, of instruments of this type, while untuned amplifiers naturally possess the disadvantage, for the purpose under consideration, of amplifying all signals indiscriminately. Nevertheless, very good results have been obtained with such amplifiers on relay reception, trusting only to the extraordinary selectivity of the latter device.

However, after many trials a really satisfactory tuned high-frequency amplifier was evolved which after some experience of its working was found to be extremely stable. As regards its efficiency, it gives an amplication factor of about 750 on three valves, with a 3 per cent factor of selectivity, i.e. a reduction of signal strength to 30 per cent of the maximum is brought about by a 3 per cent variation of wave-length. Such an instrument is naturally a very important addition to any system of reception when selectivity is desired. Further description is omitted, as this instrument may very possibly form the subject of a paper by M. Gaston Mathieu, its inventor, who has but recently left Government employment.

(3) *The "Trigger" relay.*—The essential features of this may be sketched here. Fig. 2 shows a valve system capable of maintaining continuous oscillations of a frequency determined by the values of L and C. If, however, at any selected wave-length the grid of the valve be made sufficiently negative with respect to the filament (by adjustment of the grid battery) then the system will not oscillate. If from this point the negative potential of the grid is reduced in value (i.e. the grid is made less negative with respect to the filament), then at some critical value the system will suddenly jump into oscillation: this action is known as "trigging," and the grid potential at which the trigging action occurs is known as the threshold. By the choice of suitable potentials and reaction this trigging action can be made quite sudden.

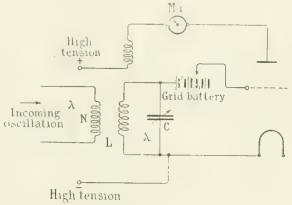

Fig. 2.

Let us now suppose that the grid has been brought to a potential just more negative than the threshold. We have seen that the valve can be made to "trig" by adjustment of the grid battery. If, however, an oscillation of the frequency of the system is passed through the coil N (Fig. 2) the grid is similarly made more positive or less negative, and the trigging action will occur.

The useful feature of the action already described

has now to be explained. By the choice of suitable values the anode current flowing through the milliammeter Ma prior to oscillation may be reduced to a very small value. When oscillations occur on trigging, this anode current will suddenly rise to a useful value, say to something from 2 to 20 milliamperes, according to the circuits employed, and this current is available for performing useful work and can be produced as described by the incoming oscillation which may be the received signal.

Fig. 3 shows this action. The anode current does,

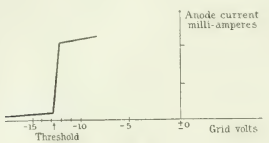

FIG. 3.

in fact, take some time to grow to the value, but considering grid potential alone the main rise in anode current can be made to occur within a grid potential change of 0·1 volt or less.

An important point to realize is that the reversal of the increment of grid potential which was sufficient to cause the valve to trig, is not nearly sufficient to cause the oscillations to stop when once started. It will be apparent, therefore, that after the valve has trigged, it will continue to oscillate irrespective of any incoming signal until it is caused to cease from oscillating by

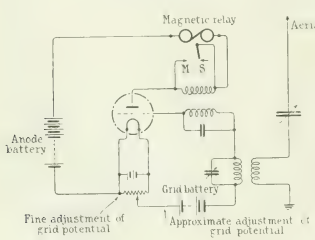

FIG. 4.

some other means. The action of causing this cessation is called "quenching" and the satisfactory quenching is one of the most difficult features of the problem.

Captain Turner in his original device inserted a relay of the standard Post Office type in the anode circuit of the trigging valve. This relay was re-wound with No. 44 S.W.G. copper wire. The relay was biased to *Space*, S, and on operating for the anode current the tongue left *Space* and crossed to *Mark*, M (Fig. 4). On making contact (*Mark*) the reaction coil in the anode circuit was short-circuited, thus causing the valve to quench. The fact of the tongue leaving M removed a shunt from the recording apparatus, thus allowing it to function. It will be seen, therefore, that for as long as the valve was trigged the relay tongue, having left the spacing contact, was vibrating on and off the marking contact. Each time the tongue struck the marking contact the valve was quenched, causing the anode current to cease, whereupon the tongue fell away from M, allowing the valve to re-oscillate, and so on.

The first contact of tongue to M after the cessation of the trigging influence finally quenched the valve and the tongue fell back to S, putting the recording apparatus out of action and leaving the system prepared for the next signal. Fig. 4 (taken from Captain Turner's paper) shows the arrangement of the electromagnetic relay.

In order to appreciate fully the excellence and the limitations of the valve relay, Captain Turner's paper should be carefully studied. It need only be said here that this relay shows a marked preference for continuous-wave signals over spark signals and is extremely selective. It should be noted that the ideal condition is when the oscillating valve circuit is precisely in tune with the incoming oscillation and not mistuned by a beat frequency. It was very early realized that the relay in its original form would fail for high speeds owing to the method employed for quenching it. In the first place, there is a definite limit to the speed of mechanical movement of the tongue of the magnetic relay. Also it is necessary, in order to obtain a quench, for the current in the anode circuit to die down to its minute non-oscillating value. This current takes time to die down, and the time taken is largely governed by the windings of the magnetic relay. For the relay to function as arranged, the windings must necessarily be of large inductance and hence the time taken to effect quenching is also relatively large and the rate of quench, or number of quenches per second, is strictly limited. This governs the speed at which it is possible to receive signals, since in order to preserve correct spacing of Morse signals it is necessary to quench about 4 times per dot. From practical experience the minimum required number of quenches per second proves to be: Number of words per minute $\times$ 2·7 approximately. Hence, for example, to receive 200 words per minute the quenching rate (q) should be at least 540 per second.

EARLY EXPERIMENTS.

As no great experience had been gained of the operation of a valve relay under practical conditions, it was decided to carry out trials over a comparatively short range in order to gain such experience, particularly with reference to the following points:

(*a*) Selectivity—freedom from jamming by other wireless stations.
(*b*) Approximate strength of signal required to operate valve relay.
(*c*) Method of reception of signal and its application to the valve relay.
(*d*) Susceptibility to atmospherics.
(*e*) Limit of speed, using electromagnetic relay as originally designed.

Fig. 5 shows the arrangement of the valve relay as used in these experiments. The terminals marked "External Indicator" were connected to a Post Office B relay, which was then operated by the removal of a shunt from across its coil. The current was supplied from the 4-volt accumulator used for heating the valve filaments.

The first field trials were undertaken by Major Fuller and Lieut. Lemon between Woolwich and Bedford from July 11th to 18th, 1919, and are of great interest as being, so far as the author is aware, the first in which wireless signals were automatically recorded on a Post Office inker at high speed. Up to this time, automatic recording was mainly carried on by means of the dictaphone. Past experiments with this apparatus, however, had shown that even when the incoming signal was as high in pitch as the cylinder would record, and the record was run at the lowest that the ear could distinguish, the maximum difference in speed covered by these two pitches limited the rate of signalling to just under 90 words a minute.

Transmission was effected at Woolwich on a 250-watt continuous-wave valve set on 1 680 metres wave-length. Reception at Bedford took place on a 2-wire field aerial 30 ft. high and 150 ft. long. Fig. 6 shows the receiving circuits (details of the valve relay are not re-drawn but may be seen from Fig. 5). The tuned aerial circuit was loosely coupled to the tuned grid circuit of a high-frequency amplifying valve. The amplified oscillations were then passed from the anode circuit of this valve to the tuned grid circuit of the first (amplifying) valve of the valve relay. A total of 3 valves was employed. Care was taken by the arrangement of coils to reduce any undesired coupling to a minimum in order to prevent the system oscillating continuously.

The result of these trials may be summed up as follows:—

Signal strength was ample. Tuning was found to be very fine and the system very selective. Very little jamming was experienced, and such little as was noticed was due to waves of a length within a very few metres of that selected. There were no very bad atmospherics, and no trouble was experienced from those which were noted.

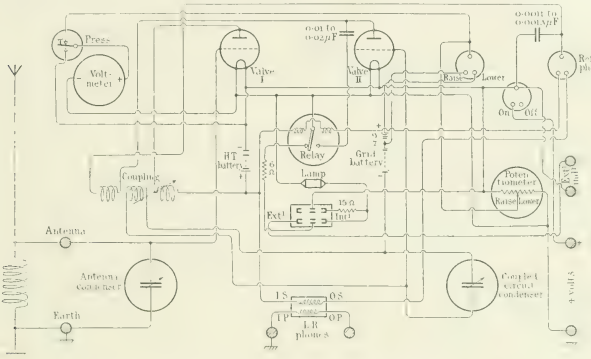

FIG. 5.—Valve relay for wireless signals.

(1) This valve relay is suitable for continuous-wave or spark signals of about 1 300–2 300 m wave-length.
(2) When tuning up, set switch to "phones," raise grid potential (by switch and potentiometer) enough to cause valve H.T. to generate; and tune in for signals in phones, making final adjustment of antenna condenser with loose coupling.
(3) Switch over to "relay"; tighten coupling, and reduce grid potential until relay just ceases to chatter. Readjust coupled circuit condenser (very slightly only) and grid potential.
(4) Maintain signalling by having loose coupling.
(5) Change of coupling, but not of grid potential, may necessitate slight readjustment of closed circuit condenser, but not of antenna condenser.

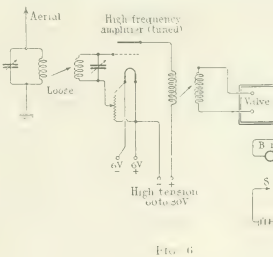

FIG. 6

No difficulty whatever was experienced up to 30 words a minute; beyond this, however, the P.O. relay began to fail. This was due to the fact that there was always

current on it, and the signal only caused an increment of current by removing the shunt from around its coils. Hence a heavy spacing bias was necessary and single current only was supplied. There was no sign of failure in the valve relay.

By changing the arrangement of the external relay, speeds up to 62 words a minute were obtained during the trials.

The following extract from a report by Major Fuller, dated 18th July, 1919, may be of interest:—

"The experiments are considered promising. The object of them—to ascertain whether it was possible with ordinary means to obtain a signal strong enough to record, while at the same time avoiding jamming from other stations and atmospherics—seems to have been fulfilled.

"*Lines of development.*—Valve relay with high-speed external quenching arrangements. This should provide a relatively simple apparatus with great selectivity and should prove capable of speeds up to about 100 words per minute.

"In view of the great advantages of a reliable high-speed recording system I think it should be recognized that the power of the transmitter should be kept high enough to ensure a reasonable factor of safety. . . .

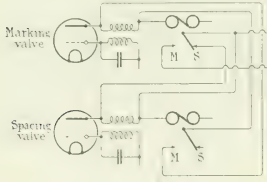

FIG. 7.

"It is desirable to use 2 aerials with each station. A large one for transmission and as small a one as possible for reception. The question of loop reception should not be lost sight of."

It has since been found possible to do all that is required with the single-valve relay, but one form of interquenching system devised may be briefly described:—

Two valve relays are employed; these are arranged to operate on the reception of a marking wave and a spacing wave respectively. They are also interconnected so that the movement of one magnetic relay quenches the oscillation in the other valve system, and vice versa. Fig. 7 shows the arrangement.

On the arrival of a marking signal the upper valve system (Fig. 7) oscillates, thus causing the magnetic relay tongue to move over to M. This operates the recorder and at the same time removes the short-circuit from the anode reaction coil of the lower or spacing valve, leaving this free to oscillate on the arrival of a spacing signal.

The arrival of a spacing signal causes the lower valve system to oscillate, thus moving the tongue of the lower relay across to M. This contact short-circuits the anode coil of the upper valve, quenching its oscillations, which action in its turn allows the tongue of the upper relay to fall back to *Space*, thereby quenching the oscillation of the spacing valve and re-setting the whole system in readiness to receive the next marking signal.

Since the relay tongue of the marking relay has only now to operate at the speed of signalling, it is obvious that the system is capable of greater speeds than that originally employed.

As a result of the Bedford trials the next two steps clearly required were as follows:—

(*a*) A faster and more certain quench.

(*b*) Means for obtaining more current to ensure reliable action of the Post Office relay operating the inker.

High-speed Quench.

It has already been explained that a high-speed quench cannot be obtained by means of the magnetic

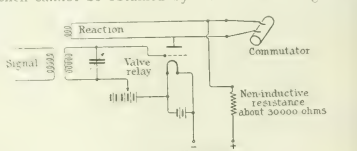

FIG. 8.

relay in the anode circuit of the trigging valve. The inductance of the relay coils is alone sufficient to prevent it. The relay was therefore removed from the anode circuit and a non-inductive resistance substituted. Attempts were then made to short-circuit the anode reaction coil, thus providing a quench, by means of

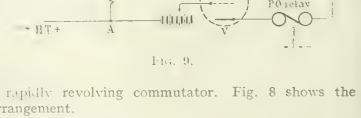

FIG. 9.

a rapidly revolving commutator. Fig. 8 shows the arrangement.

This apparently simple device was productive of a large amount of trouble in providing a really reliable and satisfactory quench, and for some time it was thought that some of the troubles, at any rate, were due to induction effects from the motor or to sparking at the brushes of the commutator. The commutator was therefore separated from the motor which was well removed from the valve relay, the drive to the commutator being by a long belt.

This appeared to bring about an improvement and was continued for a long time. A much greater improvement was produced by arranging the brushes on the commutator so that at any speed of rotation the

duration of the short-circuiting period could be controlled. With the non-inductive resistance in place of the relay coils it was found that an extremely brief period of short-circuit was sufficient to quench, and the shorter this period could be made the better and more reliable was the performance of the valve relay. This commutator arrangement provided a sufficiently good quench for further trials.

In order to get a current corresponding to the incoming signals and large enough to operate a P.O. relay at speed, the non-inductive resistance of Fig. 8 was connected to a valve as shown at B, in Fig. 9; R is of the order of 30 000 ohms. The grid of valve V is kept negative so that the current from the anode battery is very small.

150 ft. long. The trials were completely successful and perfect records were obtained at 100 words per minute. The receiving station was then moved on to Weymouth where the trials were repeated on the 11th November, 1919. On this occasion atmospherics were severe and did interfere between 6 p.m. and 9.40 p.m., after which they became less troublesome. By using a very loose coupling between aerial and closed circuit it was possible to receive through these atmospherics. A small loop was tried (1 metre square), and it was found possible to record, but the signal strength was then only just sufficient and there was no factor of safety.

It was now decided to have a more prolonged trial between London and Weymouth in order to test the system for reliability and to find out what arrange-

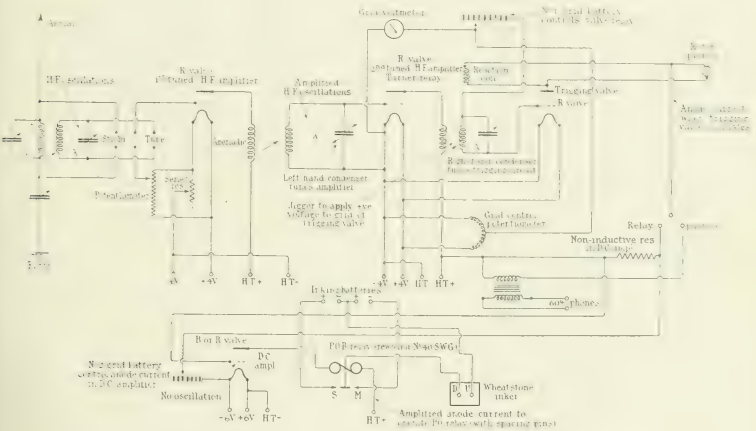

FIG. 10.—Reception connections for high-speed recording.

When a signal is received the trigging valve oscillates and its anode current traversing R may then well be about 2 milliamperes. There is then a potential difference across R of 60 volts, A being negative with regard to B. Therefore, as long as the current (or signals) endures, the grid of V is raised by 60 volts above its normal voltage with respect to the filament, or becomes 60 volts more positive. This condition allows the anode current of V (which traverses the P.O. relay) to become very large and the relay is thus operated. The relay in this arrangement is re-wound with No. 44 S.W.G. wire.

A standard receiving set was now made up and the first trials were carried out between Woolwich and Salisbury. Fig. 10 shows the receiving circuits. Woolwich transmitted on 1550 metres, using about 200 watts. Salisbury received on a 48-ft. T-aerial about

ments were necessary for the practical handling of traffic and to ascertain approximately how much traffic could actually be correctly recorded when working at definite times each day.

These trials came up to expectations. Press extracts were transmitted from Woolwich and were all written up from the Morse tape at Weymouth. It was found that the average of words recorded during the working periods, on the 5th December, for example, came out at about 75 per minute. The trials concluded on the morning of the 6th December, when during the transmitting period from 11.27 to 11.35 a.m. 901 words were recorded in 8 minutes.

About this period other methods and variations were suggested, and it was realized that very much greater speeds could be obtained. It was decided, however, to continue with the method that had been well tested

and install sets to work between London and Cologne. These sets were constructed on the same lines (see Fig. 10); on preliminary trials between London and Edinburgh, however, the quench again gave trouble. After much investigation the origin of this trouble was found to be the belt drive. It appeared to be due to some frictional effect between belt and driving pulley.

As a result of this discovery the quenching commutator was again mounted directly on the motor and care taken to make it dead smooth. The brushes were also adjusted to make a very light contact on the rotating commutator, and these precautions finally disposed of the quenching troubles, which were after all not apparently attributable in any way to inductive effects from the motor. This arrangement then was taken to be the standard method for working reliably at 100 words per minute.

A standard receiving outfit was then taken to Cologne and the transmission arranged from Woolwich. The transmitting set was provided with 5 000 volts direct current and the current obtained in the aerial was about 10 amperes. The wave-length was 1 700 metres.

According to the pre-arranged schedule, transmission was to begin on the morning of the 8th April, 1920. No difficulty was experienced and the system was in full operation that morning. During these reception

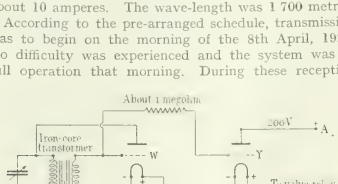

FIG. 11.

trials at Cologne the speed was raised to 150 words a minute and long Press extracts were successfully recorded.

Higher speed quench.—It has already been stated that the rate of quench (q) per second must be not less than the desired number of words per minute $\times$ 2·7. Taking 400 words per minute as the desired number, this fixes the rate of quench at 1 080 per second. The method described of using a rotating commutator with brushes becomes very difficult at this speed, especially when frictional effects spoil the result and have therefore to be reduced to a minimum. Several electrical methods have been tried and there are many others which are possible. Fig. 11 shows the most satisfactory method, which is the one that has been adopted.

The method employed consists of supplying the trigging valve of the valve relay with high-tension current in pulses and not continuously as previously. This will result in the trigging valve oscillating during only a portion of the time during which it is supplied with high-tension current and in the oscillation fading out, or in other words the quenching of oscillations, during the period when no current is supplied. The valve W (see Fig. 11) is caused to oscillate as shown at a suitable frequency, e.g., from 1 000 to 3 000 per second. The valve Y is employed as a valve in the usually accepted sense. The grid of W is connected to the grid of Y through a large resistance. The filaments are directly connected. The result is that the grid of Y is made alternately positive and negative at the frequency of oscillation of W. The high-tension supply for the valve relay is passed from A to B, i.e. through valve Y from anode to filament. It is clear, therefore, that when the grid of Y is sufficiently negative no current can be supplied to the valve relay. Fig. 12 makes the action clear.

Suppose A, B (Fig. 11) to be joined to the positive and negative respectively of a 100-volt battery. Suppose the valve W is oscillating at 1 000 periods per second

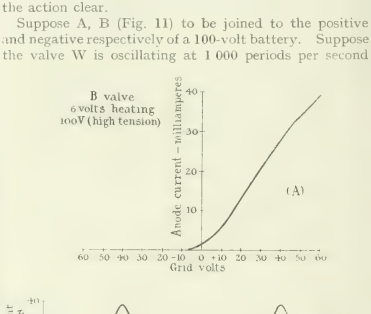

FIG. 12.

and that the energy is such that the grid of Y is caused to vary in potential from + 60 volts to − 60 volts, then if A (Fig. 12) is the anode characteristic of valve Y, B of Fig. 12 represents the current which the 100-volt battery would deliver. By adjustment of the frequency and energy of oscillation of W and by a permanent control of the potential of the grid of Y the curve B can be varied in shape at will and conditions established to obtain a satisfactory quench.

Quenching by means of this arrangement has been found to be satisfactory for all speeds of transmission of which the standard Wheatstone transmitter is capable.

Method of applying Current to Post Office Relay or Wheatstone Receiver.

In the foregoing trials the current to operate the P.O. relay was obtained as shown in Fig. 9. This current is clearly unidirectional and of about 10 milliamperes in value; hence it is not a suitable arrangement for

speeds much over 100 words per minute. The arrangement shown in Fig. 13 was therefore devised.

The valve A is the direct-current amplifying valve shown in Fig. 9. Its anode circuit, however, is modified

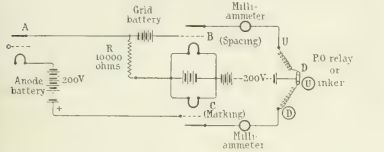

FIG. 13.

as shown in Fig. 13. The current from the anode battery now flows to the grid of valve C, thence to the filament, and thence by R (10 000 ohms) to the anode.

It is clear that when valve A passes no anode current no signal) the anode current of valve C (marking valve) is very small. The anode current of valve B high speeds these two instruments both read about 20 milliamperes. The actual value of current in each circuit varies by some 30 milliamperes, i.e. from 10 mA to 40 mA according to whether a signal is being received or not.

Although the relay or recording instrument is not actually supplied with double current, the effect is the same as that of a true double current of half the value.

With this arrangement the Wheatstone receiver or P.O. relay can be made to operate at the fastest rate of the standard transmitter.

Improved Receiver.

The evolution of the electrically operated valve quench and the circuits just described, known as a double-current valve relay, justified us in adopting these circuits, and the set of which they form a part was for some time the accepted pattern of receiving outfit. Fig. 14 gives the complete theoretical arrangement from aerial to recorder. All switches and the like are omitted for the sake of simplicity.

Referring to Fig. 14, it will be seen that the signal

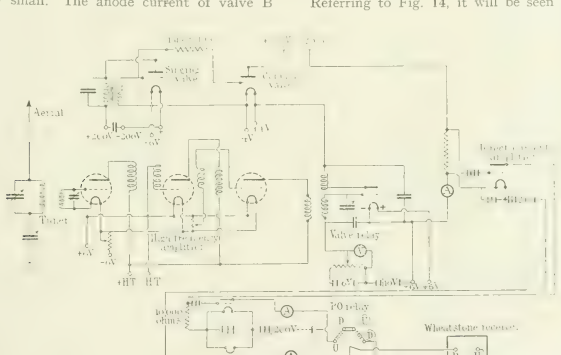

FIG. 14.

(spacing valve) will, however, be large, since the grid of B is maintained positive by the grid battery. Hence a large spacing current will flow from D to U through inker or relay, with a relatively small marking current from U to D.

When a signal is received, these conditions are reversed. The grid of C becomes positive, allowing a large marking current to flow, while the grid of B has its permanent positive potential much reduced, with a consequent collapse of its anode (spacing) current. Milliammeters are inserted in the anode marking and spacing circuits in order to allow of satisfactory balancing being obtained. In practice, when receiving a prolonged series of dots at is received on the tuned aerial, which is loosely coupled to the closed circuit. The oscillations are passed from the closed circuit to a three-valve high-frequency amplifier, the final anode circuit of which is coupled to the tuned grid circuit of the valve relay. The high-tension supply from a 200-volt battery for the valve relay is passed through the control valve, which functions under the oscillating influence of the singing valve. The anode current of the valve relay is amplified by the single-valve direct-current amplifier, which in its turn causes the double-current valve relay to supply the necessary current to operate the Post Office relay. This P.O. relay can then be used to operate any type

of recording device. Although Fig. 14 shows a Wheatstone receiver, it is of interest to note that a Creed receiver and printer have been successfully operated from the Post Office relay, thus enabling wireless messages transmitted at 110 words per minute to be received, printed in Roman characters, and ready for delivery with practically no delay.

Use of chemical or electrolytic inker for very high speeds.—The P.O. relay shown in Figs. 9 and 10 may be replaced by a chemical inker. This consists of specially prepared paper drawn between a roller and a marking pointer, the pointer and roller maintaining continuous contact with the paper. The arrival of a signal causes a current to pass through the paper, causing a discoloration, the signal being recorded in the same form as with a Wheatstone recorder. The paper, which may be the standard Wheatstone slip, has been devised. Fig. 15 shows the arrangement. Two control boards are indicated, the one marked "Signal Office" being at the position remote from the wireless station. The stations are connected by five lines, or four lines and earth. Each end is provided with a telephone which may be used at any time in any position of the control switches, also with red and green signalling lamps and a call bell. Send-receive switches are also provided. The signal office is further equipped with a manual sending key and a throw-over switch from hand to automatic working.

The method of operation is as follows:—

Transmission.—The signal office by means of the remote control makes the signal to the wireless station meaning "I want to transmit." This is done by pressing the bell push once. The wireless station acknowledges by putting its control switch to "Wait"

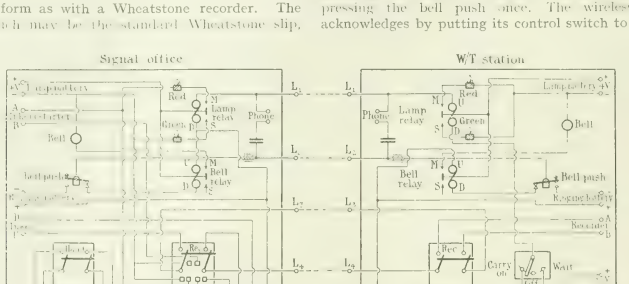

FIG. 15.—Diagram of high-speed wireless telegraphy, with remote control.

is prepared by passing it through a bath of potassium iodide solution.

The paper when used is dry to the touch, but owing to the presence of a deliquescent salt contains sufficient moisture to enable a current to pass and produce a mark by liberation of iodine. Perfect signals have been obtained at 3 000 words per minute, but it is suggested that with the present apparatus a working speed of 1 500 words per minute with a marking current of 15 milliamperes is a working proposition. This chemical inker is based on the early work of Bain, who applied it to land lines in 1870. The question of suitably preparing the paper in bulk would require more research.

Translation and Remote Control.

It is desirable, as indicated earlier in the paper, to be able to deal with the traffic at some point other than the site of the wireless station. To enable this to be readily carried out a system of remote control (while the generator is started, valves lighted, etc.) thus showing a red light at each end.

When the wireless gear is ready for transmission the wireless operator puts his switch to "Carry on," thus changing the red light for a green one, and letting the signal office know that transmission may take place.

The signal office now calls the distant wireless station by hand, and when about to send automatic sends a predetermined signal, for example six M's. The signal office then goes over to automatic and runs slip.

Reception.—The normal position of both switches is at "Receive." The wireless operator at the station (who is on watch) hears his call. He sends a warning signal to the signal office, conveying that automatic may be expected (i.e. rings bell once).

On hearing the pre-determined signal (six M's—upon the first of which he would act) the operator puts his control switch to "Carry on," which action now starts

the Wheatstone receiver in the signal office, and the signals are there recorded.

Co-ordination is ensured by the fact that the red and green lights are identical in action at both ends and a direct telephone is always available.

This system would of course be allowable only under peace conditions, and even then the provision of two pairs might be considered excessive. As has been stated earlier in the paper, control can be effected on one line and earth. However, the system, which is due to Major Fuller, is very ingenious, particularly as regards the manner in which the operator at the wireless station actually starts the terminal recorder.

Present Apparatus.

It will have been obvious that all the apparatus described up to this point is of a type requiring to be tuned throughout to the incoming signal. This has now been superseded by a type of self-quenching relay, devised by Captain Brydon, which is set to a given frequency. The incoming signal is not applied direct, but through a frequency-changer, that is, the signal is heterodyned, and the heterodyne beat is adjusted to the frequency of the relay apparatus. This last, which is called the "Autakym," is not a true Turner trigger, in that the signal effects a change in the nature of the anode current of the trigger valve rather than of its value.

As this device, once set, does not call for readjustment on variation of wave-length, and as the same heterodyne is used both for aural and automatic reception, it is of course a very handy instrument for use where reception may have to deal with working on a variety of wave-lengths, as might happen in the field.

Conclusion.

There can be no doubt that the direct recording on paper, and indeed printing, of wireless signals is now an accomplished fact.

The speed at which it is possible to work is at least as great as the speed at which the Wheatstone apparatus itself will work, and, with a specially constructed transmitter and chemical inker, speeds over 1 000 words per minute have been recorded.

The greatest range over which the system has been operated at the time of writing is 400 miles. Using 10 amperes (key held down) in the transmitting aerial a very fair factor of safety was obtained at the receiving station over this distance, so that it is reasonable to suppose that much greater distances can be traversed as the power is increased.

Possibly little is to be gained at present for general utility purposes in pushing up the speed to more than about 100 words per minute, since at this speed this means of communication would probably be capable of dealing with traffic from one wireless station to another at least as quickly as the messages could be received at and delivered from the station over land lines or cables. Also, until direct printing machines are produced capable of speeds greatly in excess of those in common use to-day, the recording of messages in Morse at very high speeds would entail so large a staff for writing up, etc., and such difficulties in obtaining repetitions, that it would probably be found undesirable. The need, however, for a printing-telegraph machine that can operate at, say, 300 words per minute from a Post Office relay is great, and the development of such a machine seems to be the determining factor in deciding the speed at which the wireless system shall operate.

Suggested uses of the system.—Many uses for the system will occur to anyone knowing its capabilities, but a few examples may be given.

(1) For the handling of telegraphic traffic to the Continent. A system independent of submarine cables and land line maintenance would *ipso facto* be more reliable.

(2) For replacing, in an important line, any sector liable to interruption, and this without reducing the speed of operation—since an ordinary P.O. relay serves as the transmitter key (at high speed) and the signal received also operates a similar relay.

(3) For Press work. Suppose, for example, a single transmitting station situated at some point in Great Britain. To this station would be sent by various channels the news of the day. At this station the news would be punched up and radiated at, say, 120 words per minute. At each important town in the Kingdom publishing a newspaper a receiver would be installed operating a direct printing-telegraph machine. By this means, one single transmission of news would result in the news being received in plain English through the country simultaneously. The enlargement of this scheme is left to those concerned, but the possibilities are immense.

The examples so far given are based on what has actually been achieved. If it be permissible to assume that the power handled can be increased and consequently the range, a startling prospect is opened up.

Discussion before the Wireless Section, 4 January, 1922.

Sir Charles Bright: In Mr. Eckersley's recent paper we were reminded of early wireless history in a way which was especially interesting to me. I remember that during the first Parliamentary Inquiry of 1906–7 concerning wireless telegraphy considerable stress was laid by some witnesses on the importance of the direct earth connection by a buried wire for the purpose of increasing the range and general efficiency. Now, however, there seems to be a reversion in favour of an interposed wire screen to overcome earth losses, and thereby to reduce the power employed. That rather corresponds to what was done in the early days to which I refer, when condensers were introduced. Now again, in Colonel Cusins's paper a great deal of important matter is brought forward. He talks of printed wireless signals. There we come to something more like business than has been introduced in most of the previous wireless papers. Colonel Cusins lays stress on the fact that high-speed wireless is practically dependent upon a really efficient printing-tele-

graph instrument. By means of Captain Brydon's self-quenching relay referred to in the paper, we learn that Wheatstone automatic working can be performed at 1 000 words a minute over a range of 400 miles. That, of course, beats anything that has been done in cable telegraphy to-day. I do not mean to say that, if it is thought worth while to put more money into a cable, it will not carry a much greater number of words than is being done at present; for it could. It would, however, not be really practicable economically or from an engineering point of view, because the cable would have to be too large for the purpose of subsequent recovery, and it would be a case of putting too many eggs into one basket. That does not apply to wireless; and there is no doubt that wireless is going to be in a position very different from that which it has occupied so far. On the other hand, "atmospherics" are still the bugbear here and especially with high-speed automatic work. We need a great many more inter-imperial communicating links if we are going to increase our trade with the rest of the Empire—it is necessary to do so more than ever now—and we shall want every possible sort of link and as many of them as may be. The days of hand transmission at 30 words a minute have gone. In the future we shall think only in terms of automatic working. The immediate main scope for wireless telegraphy, it seems to me, is in connection with the simultaneous transmission of news throughout the Empire. In that there is an immediate field; it is here that wireless cannot well be competed with; but I am inclined to agree with the Australian Prime Minister when he says that it does not matter very much what particular system of wireless we have so long as we have one which is going to get itself done; and I suppose that very likely in the future it may be more a question of wireless telephones and aircraft for effecting speedy communication, in one way and another, with the different parts of the Empire. Also we shall probably hear a good deal about General Squier's "wired wireless" before many years have passed.

Mr. R. E. H. Carpenter: This paper is of great interest as a record of work that has been and, I believe, still is being done at the Signals Experimental Establishment, Woolwich, concerning which too little has been heard in the past. In view of the fact that Creed apparatus is being used for the recording of the signals here to-night, it may be of interest to consider the question of the adaptability of this system to wireless requirements. The author mentions that it is necessary to quench about 4 times per dot in Morse working, and this naturally raises the question of the maximum amount of distortion permissible with this and with other printing telegraph systems. The Creed system is the only one that employs the Morse code, practically all other high-speed printing telegraphs employing some form or other of what is known as the 5-unit code, in which every letter is of the same length. Now, computations are frequently given in the technical Press in which it is shown that the length of an average letter in the Morse code relative to that of a letter in the 5-unit code is as 8 to 5, and from this it is argued that the speeds attainable by the two systems should be in inverse ratio. All such calculations, however, are quite futile unless full weight is given to the all-important question of the degree of distortion permissible in the received signal with apparatus functioning on the one code or the other. From the very nature of the code all 5-unit apparatus is, relatively speaking, extremely fastidious as regards the received signal form, and the degree of distortion permissible is very small. With the system which we see here to-night the tolerance of distorted signal is very great. A distortion of any signal of as much as one-quarter of a dash length in either direction is automatically corrected by the receiving re-perforator. It will therefore be seen that, where the limit of speed is set by the distortion in the received signal form, the Morse code is better adapted for the work than its shorter rival. The reasons for this fastidiousness on the part of the 5-unit apparatus are not far to seek. The code is such that signals of great length, in some cases as much as 20 units long, are at times sent, and it is clear that in the whole duration of such a signal no synchronizing action can take place. With the Morse code as used here, however, the beginning and end of every signal are made use of as a synchronizing impulse. Moreover, in the 5-unit apparatus the rotating parts which must be "corrected," that is to say, brought into correct phase relationship with the received signals, are necessarily relatively ponderous. With the machine which is being used here for the reception of the Morse code, the rotating member, which has to be jerked into the correct phase relationship with the transmitter, is one small sprocket wheel for the paper feed, weighing only a fraction of an ounce. That distortion will occur as the result of the prolongation of signals by atmospherics, or as the result of their partial suppression from the same cause, is of course obvious, apart from the difficulties met with in keying high-power arc and alternator transmitters. In connection with the method of quenching the oscillations of the valve relay by depriving it of its anode potential at regular intervals of time, it would be of interest to know whether it has been found in practice that a limit is set to the telegraphic speed obtainable by this method when long wave-lengths are being employed. In the first place, referring to curve B (Fig. 12), it is not seen how this wave-shape is attained. The curve appears to have been drawn on an assumption of a linear relationship between grid volts and time from the peak of one half-wave to that of the next. Further, it seems to have been assumed that the dynamic and static characteristics of the valve for this frequency are identical. Accepting, however, the curves as given, it would appear that the interval of time during which the anode potential is sufficiently high to cause the valve to oscillate is such that the valve would be oscillating for not more than 50 per cent of the signal duration; that is to say, at 200 words per minute Morse, with a dot length of 1/160 second, taking the figure given of 4 quenches per dot, the valve must start and stop oscillating in approximately one-eighth of this period, i.e. in less than 1/1 000 second. At a wave-length of, say, 15 000 metres, this represents less than 20 complete oscillations in one "quench," and it

is questionable whether the trigger device could be made to function efficiently and selectively under these conditions. The case is, of course, a somewhat extreme one, although the assumption, favourable to the method, has been made that the receiving aerial and high-frequency amplifier will have attained sufficient amplitude of oscillation in the first 1/1 000 second to ignite the valve relay. In conclusion, it would be of very great interest if the author could give us some further details of Dr. Brydon's device, which I believe is in use to-night.

Mr. F. G. Creed: It may be of interest to mention some experiments which I saw carried out by Captain Hovland at Christiania, Norway, in the year 1913 or 1914. He was able to record Morse signals over very short distances by means of a selenium valve illuminated by concentrated light shining through a very light grid of solenium mounted upon an Einthoven string and worked by an aerial current, which gave the same amplitude of deflection as was given by one volt through a million ohms. With that he was able to receive about 30 words a minute. Afterwards at our place at Croydon I had the pleasure of collaborating with him, and he received there up to 40 words a minute, and we were able to punch and print it. That was in the autumn of 1914. However, I thought the mechanical system was too heavy ever to give high speed, and I still think so, if the Einthoven method were employed. Another alternative method of getting this magnifying result is that which was shown at the Optical and Physical Society's Exhibition last year. It was the invention of Mr. Cox, one of the mechanicians of the Pacific Cable Board. He produced a beautiful instrument which works on the solenium-cell principle. There is a suspended coil which carried a mirror, from which a very powerful beam is reflected upon the selenium cell. I was told by Mr. Cox that he was able to get a direct magnification of 50 000 times in one operation, with a maximum period of about 40 per second, equal to 100 words per minute Morse. I dare say most of those present know something about the Orling relay. I only mention this because, in considering amplifying methods, I think we should have our minds directed to all the various means by which the result that we wish to achieve may possibly be obtained. I do not think any of them should be neglected. Personally I am a great believer in the valve, because it is easy to move electricity and comparatively difficult to move any kind of mechanical system.

Mr. L. B. Turner: This paper is in the main an account of the development of several patterns of apparatus capable of causing the feeble high-frequency wireless signal to record itself on a tape. I think the author is to be congratulated on having carried through this work at Woolwich with such ingenuity and persistence, and I am glad to have had some small share in its early stages—a share he generously acknowledges in the paper. But the devising of suitable relay apparatus was a problem which was bound to be solved by ingenious people with triodes in the hand and with coats off to the job. Behind it lie the more fundamental high-speed difficulties untouched; and the root difficulty, I think, is atmospheric interference—a dragon which rears its head not very conspicuously in the paper, but which is, I believe, waiting outside to devour us. Even with the ordinary hand-speeds of present practice in long-range work, atmospherics are the dominant factor. Hitherto the defence, such as it is, has been almost entirely the filtering process of low-decrement circuits; apart, that is, from the use of directive arrangements, which are not of general application although very useful in places. Now, as we increase the speed of signalling, or more accurately (speed) × (wave-length), we progressively lose the filtering defence on which we have hitherto relied. I can explain what I mean most simply by reference to a numerical case for which the curves shown in Fig. A have been drawn.

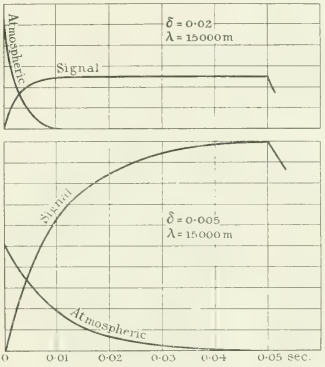

FIG. A.

Suppose we have a rather highly damped circuit, of decrement 0·02, acted upon by an incoming signal lasting for 0·05 second—a Morse dot at 25 words per minute—the wave-length being 15 000 m. The oscillation grows according to the curve marked "Signal." An atmospheric shock, on the other hand, sets up an oscillation which dies away according to the curve marked "Atmospheric." The initial ordinate of the "Atmospheric" curve is chosen arbitrarily; it depends of course on the strength of the atmospheric. If the atmospheric is strong enough to upset reception, our course has been to lower the decrement—either that of the antenna or that of a circuit loosely coupled to it. Suppose the decrement be reduced to 0·005; for the same signal we then get the new "Signal" curve, and for the same atmospheric the new "Atmospheric" curve. Lowering the decrement has hardly affected the initial value of the atmospheric oscillation, but has greatly augmented the signal oscillation; and the interference is manifestly much reduced. If, however, the speed is increased to 125 words per minute, the incoming signal ceases after 0·01 second, and interference conditions as shown by the curves are very

different. It is quite possible for a lower decrement to give worse interference; and this would clearly be so in the present case if the wave-length were rather longer, or the speed rather higher, or the decrement rather lower. Another way of stating the same fact is this: at the early parts of the curves, lowering the decrement makes hardly any increase in the rate of rise of the signal, but produces a great decrease in the rate of fall of the atmospheric. And the moral of this is that, for long-range high-speed working, some further defence against atmospherics is needed. If what I have said is based on a sound view of the relations between wave-length, decrement, and speed of signalling, it might seem that with sufficiently low speeds and decrements we could free ourselves of all atmospheric interference. The reason we cannot do so with aural reception at very low speed is that the ear strongly dislikes a gradual rise and fall of the signal, no matter how long the sensibly steady intermediate part may be. This fact, the evil of "ringing" due to excessive retro-action, is familiar to those who have used receiving apparatus with facilities for obtaining and maintaining very low decrements. I make the suggestion that a recording receiver may be of service at very low speeds with the specific object of avoiding atmospheric interference by dodging the purely psychological demand for a crisp signal, and so permitting the use of very low decrements; and I should be glad to know whether the author has considered this aspect of the functions of recording apparatus. My own experience with the instrument of Fig. 5 supports the suggestion. Further, I should like to ask him whether he has made any experiments at recording with much longer waves than the 1 700 m or so named in the paper; and if not, to suggest that comparative wave-length tests, with special observation of atmospheric interference, would be very valuable.

Professor E. W. Marchant: I should like to refer to something which Mr. Turner said in connection with the paper. He rather led us to imply that the development of the mechanical devices which were necessary in connection with some system such as we have heard described this evening, was a comparatively simple matter and that almost anybody could do it. I differ from him a little in that respect. It seems to me that the development of the mechanical devices and of all the appliances that are to be used in connection with a system of this kind is a matter of very great difficulty, and I think the author of the paper is to be congratulated on the skill with which the apparatus has been developed. I am sure Mr. Turner did not wish to imply that there was no skill about it. I attach rather more importance perhaps to that side of the subject because it is that part of electrical engineering development that has been most neglected in this country. There is one point which has not been mentioned by anybody except Mr. Shaughnessy, namely, the privacy secured by the use of high-speed systems. From that point of view I think the development of these systems is very important. It is easy for anybody to take down messages which are coming in at ordinary hand speed, but for 100 or more words an elaborate apparatus is wanted, and I think that the increased privacy obtained by the use of these systems is a matter of considerable importance. There are several very ingenious devices mentioned in the paper to which I should like to refer. One is the method of controlling transmission by adjustment of the condenser leak resistance or the grid. It is almost impossible to be quite sure that anything is new, and this has probably been tried before, but it seems to me to be a very ingenious method. Then the various methods of quenching which have been mentioned are very interesting, also the use of the marking and spacing valves, and lastly the use of the very high-speed recorders. I remember very well the description which was given some years ago of the Pollak-Virag system of recording telegraphic messages at very high speeds. A message was sent and photographically recorded on a tape at the rate of 400 words a minute. With very high speeds the line difficulties with the ordinary telegraph are enormous, whereas with wireless telegraphy there is theoretically no limit to speed.

Mr. H. J. Round: This paper records a very remarkable piece of work. I should like, however, to ask the author his opinion about one point. What does he consider to be the advantages of a trigger action over those of plain rectifiers for recording? Filter circuits and resonant circuits have been mentioned in the discussion as the same thing. The Turner trigger, using the reaction principle, is essentially a simple resonance device. Modern wireless practice has introduced the idea of the filter circuit. There are many forms of filter circuit, but actually one of the simplest forms is a series of resonant circuits in cascade. The general effect of such a series of circuits is that the peak of the resonance is not so sharp but the sides are cut off sharper. I notice that with this apparatus a filter circuit is used as well as the Turner trigger. In consequence, the apparatus can be considered to be a filter apparatus, and if that is so—and my own experience indicates that the filter circuit is the correct thing for maximum elimination of interference—where does the advantage of the trigger action lie? I notice that the author has confined himself, in all cases of transmission, to the use of a direct-current source of power; will he please indicate how he would employ grid methods of high-speed keying when using rectified alternating current, as I find the problem slightly different.

Mr. E. H. Shaughnessy: On page 246 and on page 248, the author says that the Turner relay is extremely selective. To what is the selectivity ascribed? Is it due to the putting of negative potential on the grid? If so, does any loss of sensitivity result? In other words, is the Turner relay very sensitive as well as very selective? With regard to page 249, the author has now pointed out that the references to the recording signals on the Post Office inker should be for high speed. In May 1918, Messrs. Hinton and Gill recorded all the Continental stations on a Morse inker. The Post Office referred the results to the other Departments, but they were not published owing to the war. The official letter which was sent to the other Departments stated that this opened the field to Creed, Baudot and high-speed Morse working. In the early part

of 1919 the same apparatus was used for recording the Clifden high-speed Morse. With regard to the limit of speed of working the dictaphone, in 1913 the Post Office invited tenders for a high-speed wireless station—at least 100 words a minute—and demanded a 3-day trial. The Marconi Company gave a 3 days' trial at 100 words a minute between Chelmsford and Letterfrack, a distance of something like 500 miles. The test was exceedingly severe, and the results were really astonishing. I published a description of those tests in the *Post Office Engineers' Journal* in July 1914. After the 3 days' test we told the Marconi Company that we were satisfied that they could commercially do the 100 words a minute. We then sent 20 messages at 140 words a minute which were all received without any error at all. That was done with the old spark telegraphy, and shows that the limit of 90 words per minute is wrong. Fig. 7 shows the use of a marking wave and a spacing wave in reception. The idea is briefly described in the paper; has the author carried out any experiments on high speed with this particular arrangement? The Cologne service is worked from the Central Telegraph Office with very satisfactory results, but, like all other wireless systems, when there are bad atmospherics we get trouble. However, assuming good conditions, it is possible to receive the signals from Cologne on the Creed. We have also been able to record all the Morse Cologne signals with the apparatus used for our Berlin service, which is the outcome of the apparatus that was originally introduced by Hinton and Gill for recording signals. Here are some figures of the traffic carried by some regular services. They must not be taken as the limit of what can be done, because the work is spread over a long period of the day, and they allow for all sorts of rest due to lack of traffic. One high-speed service working 6 hours a day does an average of about 40 messages per hour. Another high-speed service working 7 hours per day does about 47 messages per hour. With a key-speed service working 12 hours a day, the average was 21 messages per hour. The paper is very useful in giving such full information of the valuable work that has been done. The paragraph on page 255 under "Present Apparatus," in the absence of any description of the "Autakym," reads as though the paper had been written to describe what the Turner trigger relay will do, and then says "We do not use it any longer." Perhaps the author will tell us what the difference is between this new arrangement and the Turner trigger relay which is not now used. Under "Suggested Uses of the System," paragraph (1) says: "A system independent of submarine cables and land line maintenance would *ipso facto* be more reliable." I should rather be inclined, until the atmospheric problem is solved, to favour the cables. They can work 24 hours a day except when they have definitely broken down, but a wireless system is never certain of immunity from interference. Paragraph (3) refers to Press work. The same idea has been put forward before—there have been some trials, and the newspapers in France and Holland obtained news free. It has to be remembered that there are several Press agencies in this country. There are very many newspapers, and all the newspapers do not want the same news. In the same town all the newspapers do not want all the news. If a staff had to be kept to take down all the news and only about 5 per cent of it were published it would be found that the method was not very commercial.

Mr. A. C. Booth (*communicated*): It may interest the author to refer to the *Electrical Review*, 1907, vol. 61, page 82, wherein are described some results of Wheatstone working by wireless up to a readable speed of about 70 words per minute. The experiments were not elaborate and were carried out by quite simple apparatus by the Engineering Department of the Post Office, to see whether there was any possibility of doing anything workable at speeds above that of hand signalling. There were, of course, no valve receivers at that time, nor high-speed transmitters to carry heavy currents; moreover, the Marconi Company were not exceeding about 10 words per minute on their coherer, while the Lodge-Muirhead steel-disc receiver did not exceed 30 words per minute. The Post Office results were recognized to be a long way in advance of requirements at that time and the experiments were not continued. The results obtained by the author by using the valve, etc., have made available the Creed perforating and printing apparatus; but they also allow the use of other printing telegraph systems, particularly those using the 5-unit code. The technical Press has already described results obtained in France and Germany by apparatus using the 5-unit code, and I venture to say that before long, in fact in the near future, we in this country shall be establishing such wireless circuits. I recommend the author to get to work as soon as possible with such systems and compare them with the general working of the Wheatstone-Creed combination. As regards the results obtained by wireless working between London, Cologne, Amsterdam or Berlin, the general impression up to the present is that wireless cannot compete with wire working between those places, but is very useful when the wires are interrupted.

Dr. N. W. McLachlan (*communicated*): I do not desire to criticize the title of the paper, but I think it would have been preferable to refer to "Automatic Wireless Telegraphy at Speeds of 100 Words per Minute and upwards." High-speed wireless telegraphy may mean anything according to the experience and outlook of the individual. The author, however, states his speeds in the body of the paper and this makes the matter clear. So far as I can judge, the author's work relates to the transmission of small powers, of the order of 1 kW or so, possibly for sets which are quasi-portable. Powers of this magnitude are easily handled, and the keying at the transmitter is a facile operation. When, however, powers of 50 kW or in excess of this are to be controlled and efficacious signalling attained, the problem resolves itself into something quite complex. Viewing the matter broadly, signalling, whether by change in aerial oscillating current or wave-length (which latter incidentally involves variations in aerial current), means variations in the electromagnetic and electrostatic energies in the system. When large energy-changes

occur in a short period of time they are invariably accompanied by transients of great magnitude, giving rise to enhanced voltages and corresponding electric forces. The voltages which obtain in the steady state are usually of an adequate order, so that those which follow in the wake of the transients may be somewhat too much for the system to withstand safely. The more rapid the variation in energy, the greater the possibility of some part of the system being ruptured. Unless some scheme of signalling can be devised whereby the necessary variation in radiation from the antenna can be controlled without undue electric forces being called into play, the sending speed of high-power wireless plant as measured in words per minute will be handicapped. It is no criterion of a system to say that since it follows the frequencies attendant upon the human voice it will follow the Morse code at hundreds of words per minute. The time taken in the building up of a spoken word (in the electrical sense) is only a small fraction of the duration of that word, whereas the duration of a Morse dot at 100 words per minute may be insufficient for the aerial current in a large alternator system to attain a steady maximum value. Iron is known to respond to alternating magnetization of over a million periods per second, but it does not follow that a ferromagnetic relay will respond to a million words per minute. The point at issue is the relation which exists between the duration of a character and the time taken for the steady state to be attained. The author has cited the case of long-distance telegraphy, say 3 000 to 5 000 miles. It seems now to be general experience that owing to atmospheric disturbances, which are worst on long wave-lengths, and also to varying signal strength including fading, the power required to render the ratio of "Signal Strength" to "Atmospheric" of adequate magnitude for recording automatically for say 20 hours per day, all the year round, is very great. I observe from Fig. 14 that the recording is accomplished by means of a Wheatstone receiver, which implies the "dot and dash" system. I do not doubt that this scheme has proved satisfactory, but there are three salient reasons for preferring undulator tape to the dot and dash method. These are as follows: (1) A letter is not entirely obliterated when an atmospheric arrives, and it is possible in general to read the tape unless of course the atmospherics are unusually severe. With the dot and dash system the effect of an atmospheric is either to hold the ink wheel on the paper, which is equivalent to blurring, or to bring it off the paper altogether, which splits the letter. Either of these occurrences is fatal to the legibility of the tape. (2) The tape is, with a good undulator and a little practice, more easily read than the dot and dash tape. (3) It is possible by inspection to determine whether the Morse transmitted from the distant station is "light" or "heavy." With automatic transmission it is apt to be light, especially on dots. If the Morse received at the wireless end has to be relayed to a land line without intermediate re-transmission, this property of the undulator is invaluable and serves as a check on both out-going and incoming traffic. These three points are of major importance in a commercial station.

I should like to ask the author a number of questions which arise in connection with his paper. Is the Cologne service in operation continually, i.e. for 24 hours per day, and is the traffic sent in code? If the latter, how many RQ's would be expected in a message of 1 000 words? Is the ratio of signal strength to atmospheric so large that the effect of atmospherics upon the recorded signals is *always* negligible, or are there times when the atmospherics penetrate the system and cause trouble? Assuming that atmospherics are troublesome, what is the behaviour of the Turner relay? How are the received signals in this country affected by the large spark set at the Eiffel Tower; is there any sign of jamming or can recording be carried on as usual? I presume that the system described is a simplex one, which of course is very much easier to manipulate than duplex. In commercial work using simplex, serious difficulties arise owing to the inability to break in when the transmitting end is at fault, and the net rate of sending is therefore reduced. The Turner valve relay is generally understood to be susceptible to change of wave-length, and I should like to know if any precautions are taken, especially during bad weather, to ensure that the transmitted wave-length is preserved constant. With a highly selective receiving circuit at 1 700 metres, this point seems to be rather serious for continuous operation, but I shall be glad to have the author's view on the subject. His remarks regarding the chemical method of recording are highly interesting. Commercially, of course, speeds of 3 000 words per minute are out of the question. I assume that for such a speed the transmission was effected by cutting out the Morse characters on a disc and revolving it at high speed. Was it actual wireless transmission, and, if so, on what wave-length? With a moving-coil galvanometer tuned to several thousand periods per second a speed of 920 words per minute has been obtained photographically by the General Electric Co. of America. As the author is doubtless aware, photographic methods have good points, but they are too costly and require too many accessories of a wet nature to be of commercial utility. I agree that there is a need of a high-speed printer, but I fear that the author's figure of 300 words per minute is rather too ambitious in the present state of the art. The great drawback to such a speed is the large inertia of the moving parts and the forces required to operate the printing mechanism. Multiplex printing telegraphy at 100 words a minute, or even less, on each line will, I think, fully meet most commercial conditions likely to arise, and it is my opinion that Morse will ultimately disappear and be replaced by direct printing.

Lieut.-Col. A. G. T. Cusins (*in reply*): Before dealing with the various points raised by individuals in this discussion, I desire to draw attention to the third paragraph of the paper. Various tilts have been run at the atmospheric dragon, but up to the present most of the entrants have had to retire more or less hurt and with their theories a bit dented. Without admitting that the beast is invulnerable, there seems to be little doubt that for some time to come he is better avoided than dared, and, until the real point at which the *coup de grâce* may be delivered is finally located

we shall have to take advantage of his periods of comparative quiescence and travel in regions over which his sway is less complete. On the whole, the shorter wave-lengths of 3 000 metres and under seem freer from such disturbances than those above, and although I did not specifically mention it, this is one of the reasons for my suggesting a system of short range—and therefore short wave-length—working, in which long-distance messages would be relaid from point to point. There seems, moreover, to be no reason to doubt that the difficulty of communicating from point to point varies, quite apart from the actual difference in power required, at a rate greater than the first power of the intervening distance. And advantage should be taken of the fact that the hours of the day during which atmospheric disturbance is serious are different in different localities. Against the system it may be urged that there would inevitably be local congestion of traffic. It is only by automatic reception and retransmission that such congestion can be cleared without danger of mutilation of messages. Since the paper was read it has come to my knowledge that such a system is already being worked on a somewhat extensive scale in Germany as an everyday working adjunct to the telegraph system of the country.

Sir Charles Bright voices an undoubted fact when he says that we require more inter-imperial communication links. The demand for communication will always keep pace with the supply, and all that can be provided, whether by specially constructed cables capable of high-speed working and superimposition of high frequencies, or by the extension and ramification of wireless or by any other means that may be devised, will be rapidly absorbed. The cry will always be for more, and the difficulties will lie not so much in competing for traffic as in coping with it.

Mr. Carpenter asks whether a speed limit is set by the rate of quench when using long wave-lengths. We have not so far used long wave-lengths. Wheatstone working has been found quite feasible at 400 words per minute on a 2 500-metre wave-length. The characteristic shown in curve B, Fig. 12, is the static one.

Mr. Turner also raises the question of working on long waves. If time and personnel are available, there is a very large field of investigation to the end of correlating wave-length, decrement and speed of operation, more particularly in countries where atmospherics prevail. The possibility of working at very low speeds, using, say, a siphon recorder, has not been overlooked. In connection with this, the deliberate inclusion of a mechanical device the inertia of whose parts will respond only to a comparatively sustained signal regardless of intensity, which would in fact respond to a Morse dot but not to a more powerful atmospheric of shorter duration, is an expedient perhaps worthy of consideration, though admittedly not "wireless."

Mr. Round questions the advantage of "trigger" action. It serves as a convenient method of introducing current changes of sufficient magnitude to operate mechanical appliances. When used with a not too sharply tuned high-frequency amplifier it is found to give sufficient selectivity to separate the marking from the spacing wave of an arc station and is therefore also suitable for working on continuous waves at close intervals of wave-length. Our experience is that on the whole it is economical in valves for the effect produced. With regard to alternating-current working, a very satisfactory system of high-speed keying, using a relay gap of 1/32 in. has been evolved, operating on a set whose primary input is three-phase, 50-period, 250-volt alternating current. The full power generated for all purposes is 6 kW, and the high-tension supply to the oscillating circuit 9 000 volts maximum. The arrangement has given very good results on the Aldershot–Cologne system.

With regard to Mr. Shaughnessy's remarks, the question of sensitivity and selectivity of the Turner valve relay was, I think, very fully dealt with in Captain Turner's paper (Sec. 7).* No actual experiments on high speed have been made with the marking and spacing wave, as the Army does not at present contemplate the use of such a system of transmission. The records of dictaphone working are very interesting, and quite surpass those within our experience. As regards the other systems described, it must be borne in mind that military apparatus has to be compact and portable. That we have described one system and shown another is fair comment. The statement as to the efficiency of the various high-speed services omits any mention of the power used and the distances traversed. There is no doubt that the Aldershot–Cologne service is very much "under-powered." It is, in fact, stretched almost to the limit, using only about 1½ kW generator output. The fact that even so very satisfactory results have been obtained augurs well for the system when operated in a more generous manner.

Mr. Booth refers to the work which has been done in France and Germany with the 5-unit code. In the latter country in particular, an extensive system is being worked regularly and appears from all accounts to be very reliable. It is pleasing to hear that in this country also we are in sight of something similar; but I do not share the doubts as to the feasibility of satisfactory across-sea working, nor, apparently, does Mr. Shaughnessy. The inference that wireless is merely to be regarded as a stand-by is, I submit, to place it in an invidious position, and to tend to impose on it the handicap of working in what one may call the newly mobilized state. As regards the comparative advantages of Wheatstone–Creed, Baudot, Siemens–Schnell or any other printer-receiving apparatus, these are not under discussion. I think Mr. Round asked: "Given nine valves, what can we do with them?" Well, we can produce current in practicable quantities for the electro-mechanical engineer to work his will with. So far as Army working is concerned I do not think anybody wishes to contemplate a war calling for anything worse than a Post Office inker.

Dr. McLachlan raises the point of what may be termed "key shock," which is analogous to water-hammer action. This is an old enemy of the wireless engineer, and it may be interesting to record the fact that, in the early wagon sets used in the Army, difficulty was experienced at first owing to the actual failure

* "The Oscillatory Valve Relay," *Journal I.E.E.*, 1919, Supplement to vol. 57, p. 50.

of the crank shafts of the engines under the torque blow caused by the violent electrical variations due to keying. This trouble has been overcome in recent sets. With power commensurate with the range there is reason to believe, judging from the Post Office experience, that RQ's would be very rare. Spark jamming has not caused trouble. The Turner relay, and also the "Autakym," exhibit a marked preference for undamped waves. But atmospherics undoubtedly cause interference when more powerful than the transmitted signal, though a certain immunity is enjoyed owing to the mechanical reluctance of the terminal instruments, which also limits the speed of action. The greatest speed of actual wireless working has been about 1 600 words a minute on about 1 500 metres, if I remember rightly; 3 000 words a minute was a test of the recording power of the paper strip used. Very high speeds might be a means of dodging atmospherics. This is a point I have not raised. But if as much as 10 per cent of a single message is obliterated, it is 9 to 1 on any symbol getting through. If repeated 4 times at 400 words a minute, we should still have a message at 100 words a minute and the chances of each symbol getting through unmutilated are raised to the order of thousands to one. This point may be worth considering. Constancy of wave-length is a matter to which considerable attention has been paid. No difficulty has been experienced in operating the relay with the sets produced, though the relay is very fastidious. The ready applicability of Morse to all forms of signalling probably renders its use permanent so far as Army work is concerned. No attempt is made here to judge the relative merits of the various other systems available.

DISCUSSION ON

"TELEPHONE LINE WORK IN THE UNITED STATES."*

North Midland Centre, at Leeds, 29 November, 1921.

Mr. T. B. Johnson: It should be remembered that though there are big cities in America they are separated from each other by large spaces, and if we in England tried to adopt the overhead system described in the paper we should be stopped by the towns and cities through which we should have to run, so that finally we should have neither an underground nor an overhead system. Fig. 1 shows the organization of an associated company. I shall confine my remarks to the engineering side entirely. One would expect to find that engineers were gathered under the control of the General Engineer, but such is not the case. It is true that under the Chief Engineer we find a certain number of engineers, but we find other engineers under the General Superintendent, who is apparently entirely independent of the Chief Engineer. I suggest that in England we can show something considerably better than this, every engineer being graded under the Engineer-in-Chief, and this is, I suggest, the proper place for him. In connection with motor transport, on page 108 it is stated that there are 250 men engaged on the maintenance and repair of 1 000 vehicles, an average of 1 man to 4 vehicles. That appears very excessive. Certainly we have not developed motor transport in England to such an extent as has been done in America, but we have a large fleet of motor cycles in each district in England and we do not need maintenance men on such a costly scale. If one company has no fewer than 250 men engaged on the repair of vehicles it would seem necessary to have a motor engineer, but there is no mention of such an officer in Fig. 1. The author refers to subways. Only last week Mr. Henzall, our City Engineer, drew attention to the constantly increasing cost of attending to faults in water mains. Roads are being made more substantial, and consequently they are much more costly to tear up. If only we could get, when streets are being widened or re-made, subways for gas and water, power mains, telegraphs, telephones, etc., the lot of all engineers would be lightened considerably, and it would be a good investment for the towns carrying out those works. On page 110 it is stated: "Another important point is the prospect of promotion to the higher grades for all ranks. It is a fact that any position in the Bell System is open to anyone who becomes qualified for it." A similar statement could be made in regard to the British Post Office.

Mr. F. E. Gibbins: One of the greatest differences between American and British practice is in the use of aerial cables. In America apparently it is the practice to use aerial cables for main lines. In this country we use them chiefly for the small towns, in which, whilst the development is not sufficient to justify underground cables, it is more than sufficient to overload open-wire lines; but our greatest objection, I think, to the use of aerial cables along country roads is the great difficulty which we experience in dealing with trees. I notice that one of the arrangements made before erecting aerial cables in America is to remove trees immediately adjacent to the line. Our powers would have to be strengthened very considerably before such cutting would become possible in this country. On the other hand, where we have to erect aerial cables I think we have something to learn from the paper. Undoubtedly some of our troubles in the

* Paper by Mr. E. S. Byng (see page 85).

past have been due to the fact that air spans are too long. Whereas the length of spans varies from 100 to 150 feet in America, in this country it varies from 60 to 90 yards. I should like to ask the author if he would explain more fully the meaning of the statement: "If ultimately the route is to carry two cables, the strand for the first is erected on the same side of each pole throughout." It seems to me that this means erecting the suspension wire in some cases on the outside of the bend. That does not appear to be a satisfactory method, as at certain points the cable would pull against the pole. In regard to patent stays, we have tried them but have not found them satisfactory. We adhere to the method of using wood blocks, and even with these it is not unusual to find a certain number of drawn stays after storms. I should like the author to say whether that is the experience in America. In certain extreme cases wood blocks are used there, but in England they are invariably used. The method of binding wires into the insulators is one which we discarded 25 years ago. Before the present method of binding was adopted, experiments were made which proved that the tape and binder was much more effective than the old method, as it prevented to a great extent the "running through" of the wire after a break. Experience has since shown that it has to a great extent reduced the number of faults due to broken binders, and the tape, by preventing the wire from chafing against the insulator, has reduced the number of disconnections.

Mr. E. H. Farrand: I propose to deal with that part of the paper which refers to underground work. The impression obtained from the paper is that the conditions in America are far more favourable to telephone engineers than anything we have in this country, as regards both overhead construction and underground construction. In the first place, the use of such apparatus as the mechanical excavator appears to me to be absolutely impossible in England. I cannot imagine any main road, or in fact any piece of country road, where such an excavator could be used without cutting high-tension cables, gas and water mains, electric mains, etc., every few yards. In the paper, standard manholes are shown which are stated to be made to templates and therefore can be constructed in numbers almost exactly alike. According to the figures it is possible to get the line of ducts in the manholes central, or almost so. I have constructed a great many manholes and I have not found two where the line of duct could be got in the same place in the manhole. Our difficulty is to find any position in any main street in a city like Leeds where we can place a manhole; and to build them to a template is practically impossible. Further, the types of conduit described in the paper are much on the lines of Post Office practice, with the exception that of late years we have done away with the square formation of ducts; that is, the hole in the duct is not square but round, the reason being that we find it easier to align those ducts and to get round bends with them, at the same time keeping them joined together in such a manner as to exclude water. It appears to me that lines of square ducts fixed together with dowels as shown in the figures can be adopted only where they can be laid in straight lines. In a town a straight route is almost impossible to obtain. I was interested in the method of boiling-out joints described in the paper. One firm of contractors, with which I believe the author is now connected, do boil out the joints with wax, but the bulk of our contractors do not. There are certain disadvantages and certain conditions which may not apply in America, but do apply here. The first is the danger that occurs of spilling the hot wax when taking it down into a manhole. This danger must be greater in England, where the entrance to a manhole has to be planned according to the conditions found in the ground where it is constructed, than in a country like America, where apparently manholes can be constructed with a clear entrance. Some 10 years ago when a cable was laid between Bradford and Leeds one or two accidents were caused by the spilling of boiling wax. Fortunately no one was injured. Another disadvantage we found was that the waxing of the paper tends to make the colours difficult to distinguish, especially in the poor light which is available in our manholes. In addition, if the wax is made too hot it causes the paper to be brittle: the jointer breaks it and has to put a new piece of paper on. This is not satisfactory. On the other hand, there is no doubt that the waxing of a joint does prevent to some extent damage accruing from defective plumbing spreading rapidly in the cable and throwing it out of action in a short time. I think that object is attained much better by our method of pressure-testing which shows, in addition to defects in the plumbers' wipe, any defect in the sheath. Despite what the author says about defects in the sheath, a certain number do arise on every job, due perhaps to a man driving a nail into it when nailing up the drum, and to small particles of foreign substances getting into the lead of the cable sheath during manufacture. Where, however, the cable has been under an air pressure of 20 lb. per square inch, those defects are shown and are remedied. With the waxed joint and no pressure-test, the defect would after a time admit water and the cable would break down. Of the large number of cable contractors now working for the Post Office the greater number do not use the boiling-out process. They are given the option and they prefer not to use it. It may be said that we do not get such high insulation results, as one of the advantages claimed for the boiling-out of joints is that it prevents damp getting into the cables during jointing. We have just finished a main cable from Leeds to Harrogate and the test-results show an insulation of 40 000 to 50 000 megohms per mile. I have never seen a waxed cable that has given such high figures, and I am very doubtful if anything better could be achieved by the boiling-out process. I should like some further information as to the speed of jointing. The rates given in the paper are, compared with our practice, exceedingly high. For instance, it is stated that 150 pairs or 300 10-lb. wires have been jointed in an hour by one man. From my observation each wire joint in England entails 6 separate operations, and 1 800 operations per hour needs very nimble fingers. Of course, if the mate is doing a large part of the work—such as stripping the ends of the wires and so on—then there are two men employed. I

should also like some information as to the joints made when fixing loading coils so as to allow for additional loading coils. The next point to which I want to call attention is the installation of cable in ducts. The author states that the speed of pulling a cable through a duct in America is 50 ft. per minute. I should like to know whether that speed has any ill effect on the sheathing of the cable. The average rate used by most of the big contractors in England is only 20 to 30 ft. per minute, and it will thus be seen that we could not hope to do anything like the 4 miles of cable in one working day of 10 hours mentioned in the paper. I believe that what is called a record by most of our contractors is about one mile of cable in 10 hours. The average in England is more like 7 or 8 cable-lengths per day. This is good work. We have not all the mechanical appliances which they have in America, but we have motor winches and motor tractors. It is simply in connection with the speed of pulling the cable through the duct that apparently any great saving can be effected.

Mr. R. M. Longman: In connection with the use of telephone lines and power lines on the same poles, I should like to know the voltage of the power lines, their height above the telephone lines, and the safety precautions taken in case of their falling across the latter. Are the bulk of the telephone lines merely bare wires or is one telephone lead-covered line run into the small connecting box to which the consumers are attached? What regulations govern the combined use of such poles, and what are the factors of safety, the wind pressure, and the ice loading allowed on the large lead-covered cables used in the main transmission? I am of opinion that the large lead-covered cables will last longer and have a much more satisfactory life, than the small lead-covered suspended cables which we have been using in this country. We have experienced considerable difficulty due to fracture of the lead, but I think that with cables of 2 inches and upwards in diameter much less trouble will be experienced from this cause. Can the author say whether these cables are coated in any way to prevent corrosion?

Mr. A. E. Jones: Mr. Farrand is interested in telephone lines from a power company's point of view, mainly, perhaps, because of their liability to be damaged by high-voltage lines. Aerial telephone cables $2\frac{1}{2}$ inches in diameter were mentioned but I cannot recall any of this size and weight being erected, nor can I imagine any telephone engineer undertaking the job when underground cables are possible or smaller cables are available. I do not see any mention of the method of staying long routes or as to the intervals for fore-and-aft and wing stays. With regard to "guy anchors," my experience is that their efficiency depends on the kind of ground. They hold very well in clay. I should have liked some details of the method of handling serious breakdowns of aerial routes, but I suppose the superabundance of mechanical transport, equipped with pole-lifting derricks and other appliances, would enable American engineers to repair damage very quickly without recourse to "interruption" cable, although I favour the use of cable or anything else if only the long-distance toll calls can be got through. I understand that the cross-arms are spaced at 24 inches, but I take it that the slots are staggered at this distance on each side of the pole, the result being a 12-inch spacing. I cannot follow the mechanical considerations in this method, but it probably weakens the pole. It would be interesting to know the type of protector fitted to the bridle wires, as I understand that American practice is to stop the lines outside rather than inside the premises. Is it the practice in America to run the telephone leads underground for individual residences? I suppose block-wiring is used much on the same lines as in this country. On page 95 the cable is shown being "dressed" for the grip by making circular rings. Is this considered a better method than that of dressing down the cable for the whole length of the grip? For aerial cable suspension wires I am not clear as to whether the false dead-end shown in Fig. 9 (*c*) is better than a direct termination of the strand. The author makes no mention of one of the most prevalent troubles experienced on long open lines, caused by a very small spider which, using its web as a means of transport, is caught by the wires. The web invariably spans two or more lines, and myriads of these tiny strands are frequently soaked with moisture. The spider builds its home inside the insulator and transforms it from a "double shed" into a "single shed." The effect on line insulation is very serious, and long-distance circuits are frequently inoperative during damp weather. It would, I am sure, be of interest to line engineers to know if an effective and inexpensive remedy has been found.

Mr. G. H. Hoole: I should like to know what are the relationships between the different telephone companies and the road authorities. I notice that in America lump-sum payments are made in final settlement. That idea has been considered in England. I should be glad if the author would state approximately how much is offered to the grantors. There are undoubtedly big advantages in that arrangement, amongst others a very great saving in clerical labour. Can the author say if there are a large number of lump-sum payments? The tree-cutting clause is interesting, but in England we are protected to some extent in the case of trees on private property overhanging roads. We have not much protection on private property, which we avoid if possible. On the question of transport it is stated to be a simple matter in America to prove economy by the use of motor transport, even though there is not a good railway service. Here we have a good railway service, and we have found it to be very economical to promote a transport system, although shorter distances have to be patrolled. Motor cycles are stated to be used to a limited extent for maintenance purposes. I was surprised to hear that because a motor cycle with a side-car seems to be the best capital outlay for maintenance work. It is so easy to run with box fittings instead of a side-car, to carry stores and sufficient tools. In England this combination has been found extremely useful, and I should have thought it would have been used more in America in view of the distances to be covered and the isolated stations.

[The author's reply to this discussion will be published later.]

UTILIZATION OF EXHAUST STEAM FROM ELECTRIC GENERATING STATIONS, AND COAL ECONOMY.

By C. Ingham Haden, Past President of the Institution of Heating and Ventilating Engineers.

(*Paper received* 14*th December*, 1921; *read at a Joint Meeting of* The Institution *and* The Institution of Heating and Ventilating Engineers 19*th January, and before the* North Western Centre 21*st February*, 1922.)

Summary.

The paper calls attention in the first place to the consumption of coal in the United Kingdom, and the loss of heat which is taking place in electric generating stations.

It suggests the combination of heat distribution with the generation of electric current as a possible means of using the coal to better advantage.

It further proposes the conversion of some of the existing generating stations which would be shut down under the super-station scheme, and which are conveniently situated, into heat-distribution stations generating electric current as a by-product, and the linking up of such stations with the super-stations.

The paper gives some particulars of a typical district showing the probable heating and lighting loads, and finally describes installations already carried out in this country.

The subject of this paper is of the highest importance; in fact, regarded from a national point of view, I think there is no subject which concerns so many matters of vital necessity to the individual and therefore to the nation. It deals with heat, without which we could not exist; it includes light and power and, to a certain extent, cooking, and the foundation for all is our national asset of coal.

As engineers, we are all aiming at efficiency with economy. I hope, therefore, that any statements made in this paper which may be considered to be criticisms of existing practice or present proposals may be received in the spirit in which they were written, viz. to arrive at the best results when all the varying conditions are taken into consideration.

The amount of coal used annually in this country for all purposes, given in the Final Report of the Coal Conservation Sub-Committee, is approximately 189 million tons, of which about 35 million tons are used for domestic purposes, 118½ million tons for manufacturing purposes, 18 million tons for the manufacture of gas, and, though no separate figure is given for the amount needed for generation of electricity, I am informed that this would be about 10 million tons, and I assume this to be included in the coal used for domestic purposes.

If we express the calorific value of the coal as 100 per cent, we may assume the average thermal efficiency obtained from the coal used for domestic purposes to be 50 per cent.

The total tonnage given above must be taken to include all coal used in heating systems with a varying higher percentage of efficiency, otherwise the total figure would be lower; for instance, if only open fires and ranges were included.

For the manufacture of gas I cannot do better than quote Sir Dugald Clerk's figures, viz. gas 25 per cent, coke 40 per cent, and tar 6 per cent, a total of 71 per cent, and here it must be noted that a considerably larger proportion represents the "by-products," and 65 per cent represents the thermal efficiency at the gas-works. From the consumer's point of view the figures need adjustment. Sir Dugald Clerk says that the gas converted into heat may reach an average efficiency of 42 per cent * and, if the coke has an average efficiency of 75 per cent, these together represent a total thermal efficiency of 40·5 per cent, excluding the tar.

The number of British thermal units in the coal converted into electrical energy in connection with electric generating stations is approximately 5 per cent of its calorific value, but I believe that it is hoped in new large stations to improve this figure to 8 per cent. Comparing this with the manufacture of gas, one naturally looks for the by-products, only to find that they are an expensive burden not easily disposed of. I am sure it is not generally known what colossal figures are involved in this matter, and what enormous waste is taking place in so many stations.

With the most up-to-date boiler plant it is claimed that an efficiency of 80 per cent is obtained from the coal, and, assuming the calorific value of the coal to be 14 000 B.Th.U.'s, 20 per cent or 2 800 B.Th.U.'s is lost in the boiler, and 90 per cent of the remainder, or 10 080 B.Th.U.'s, in the generating plant; i.e. out of a total of 14 000 B.Th.U.'s, 2 800 + 10 080, or 12 880 B.Th.U.'s, are lost, and only 1 120 B.Th.U.'s are converted into electrical energy; in other words, for every 100 tons of coal used in this way the heat equivalent to 92 tons is lost, and, as the approximate total used in generating stations in the United Kingdom is 10 million tons per annum, the huge total of 9 200 000 tons represents the approximate value (expressed in tons of coal) of wasted heat; this quantity, at an average price of 30s. per ton, amounts to £13 800 000 out of the total of £15 000 000 paid for the coal.

As the electric current is sold under statutory powers, we as users have to pay the proportional cost of all this heat in the price per unit, but that does not fully explain why the cost of the units sold is so high. In most generating stations condensing plant is employed, with cooling towers if no other source of water is available. I believe that it is the general practice to employ electrically-driven pumps for the condenser circulating water, and when cooling towers are used

* *Gas Journal*, 10th February, 1920.

these pumps absorb a considerable percentage of the current generated. For example, a 15 000-kW set (maximum rating 18 000 kW), with condensers and cooling towers, using, say, 17 lb. of steam per kilowatt-hour, requires 1 700 000 gallons of circulating water per hour to be raised to the top of the cooling towers. As all this energy is wasted, the price of the units actually sold has to cover the cost of the units used in this way. This does not, however, complete the account, as in some cases large fans are used to blow away the heat from the cooling towers. In one station for plant of the above size I have seen 24 fans, absorbing 540 h.p., used for this purpose, thus further reducing the saleable units.

The water lost in vapour is another expense which has to be met. In the station referred to above, the water required to make up the loss for the 15 000-kW set is 720 000 gallons per day of 20 working hours, or a total of 262 800 000 gallons per annum, costing, at 6d. per 1 000 gallons, £6 570.

Assuming that cooling towers are in daily operation for generating sets of, say, 1 million kW in the same ratio, the water required to make up the loss would be 14 600 million gallons per annum, and this, at 6d. per 1 000 gallons, would amount to £365 000.

These facts and figures being assumed correct, the question is: Can anything be done to lessen the waste, or in what way can the heat be utilized? This is a difficult problem, but its complexity should not prevent an attempt being made to deal with it as far as possible.

The first main difficulty is to find a market for the heat, and, if this is obtained, the further difficulty arises of co-ordinating the loads. Heat for warming houses, institutions and public buildings is required for only 6 to 7 months of the year, and with our moderate and variable climate the heat load would vary tremendously. There is, however, a constant demand for hot water throughout the year, the quantity depending upon the type of buildings in any locality. The possibility of utilizing the heat depends very largely upon the position of the electric generating station in relation to that of other buildings requiring heat or hot water, on account of the difficulty and cost of transmitting the heat to any great distance. Some electrical engineers, therefore, advocate the use of electric current for all heating and domestic purposes.

Everyone is bound to admit the convenience of an electric supply for heating, cooking, etc., its cleanliness and adaptability, also that the losses in transmission are less, and that many difficulties inseparable from the laying of large steam or water mains would be eliminated, but at what a cost! The consumer wants heat and, in order to supply it, the average electrical undertaking buys coal, throws away about 95 per cent of its heat, and transforms only about 5 per cent into electrical energy. This means that for every electrical unit (equivalent to 3 411 B.Th.U.'s) about 5 lb. of coal at 14 000 B.Th.U.'s per lb., or a total of 70 000 B.Th.U.'s, has to be consumed. The cost of running auxiliary plant at the generating station, and losses in distribution still further reduce this small percentage. With present methods, therefore, it is a most wasteful form of heating and quite impossible if coal is to be conserved.

In the light of the foregoing figures, is it possible to provide a more economical type of plant so as to obtain a higher total efficiency?

The combination of heat distribution with the generation of electric current will give a higher heat efficiency than any plant already named. It will be noticed that I place heat distribution first, the reason being that the heat load is the deciding factor in the proposition for economy.

The approximate quantity of coal consumed for domestic purposes in this country was given as 35 million tons per annum. As no separate figures are available it can only be assumed that of this amount 10 per cent, or 3½ million tons, are used for central heating and hot-water-supply plants. If the coal were used in the most economical type of heating apparatus an efficiency approximating to 80 per cent might be obtained. If that total tonnage had to be used it would be possible to provide steam boilers and electric generators, the electric current being regarded as a by-product. Allowing 8 lb. of steam per lb. of coal, and 115 lb. of steam per kilowatt-hour, with a back pressure of 60 lb. per sq. in., 155 kWh would be obtained for every ton of coal.

With plant arranged on these lines about 3 per cent (only) of the heat in the fuel would be transformed into electrical energy; that is, about 3 per cent of the coal consumption would be utilized for electricity generation, and the total consumption should be increased correspondingly in order to obtain the same heating duty. For every 100 tons now used for heating purposes, 103 tons would be consumed, making the total 3 605 000 tons. On the above basis this would produce a total of 15 965 kWh for every 103 tons of coal consumed, and, if it were possible to use the whole of this fuel under the ideal conditions, the total number of kilowatt-hours, if sold at an average price of 2·2d. per kWh, would produce an income of about £5 122 000.

I am aware that it is not generally possible to place an electric generating station in a central position so that it can be used as a heating station, because a site is usually chosen close to a railway, river or canal, and often on the outskirts of a town or city.

Super-Stations.

A good deal has been heard about the advantages to be obtained by dispensing with a large number of existing generating stations and serving these districts from the super-station by high-tension mains. How, therefore, do these proposals affect the question now under consideration?

I believe I am correct in saying that the positions chosen for these super-stations are close to some waterway, it being considered more necessary to be near water for condensing purposes than to be near a coal mine, and for the obvious reason that the heat can be washed away and cooler water obtained for the condensers. Is this, therefore, an entirely sound

and economical proposition? In reply to such a question I would say that no scheme can be considered complete which does not make some provision for the utilization of the waste heat.

If the super-station is built in a district where there is no possible use for the heat, then the conclusion is that the position is not rightly chosen, unless the electrical load exceeds the possible heat load in the district to be served. The area which can be served electrically from one of these proposed stations is, of course, vastly greater than is possible for the distribution of heat, but the scheme involves the scrapping of many of the existing generating stations within the areas, which seems a most calamitous proposition. A possible alternative is to retain such of the existing stations that can be usefully employed as heat distributing stations, utilize them to their full capacity, and, if there is a greater demand for heat, then provide additional heat stations, using them also for generating electric current as a by-product.

Having completed a careful estimate of the heat load (and of course every plant might be made capable of extension) then by linking up these stations with the super-generating station the balance of the electrical load would be made up at the super-station. This arrangement makes it possible to provide for the varying heat load, and to bring into commission a larger proportion of the plant at the super-station during the summer, when the minimum heat load would occur.

If the lighting load of an existing station is larger than the power load, this lighting load will be found to coincide more closely with the heat load.

I understand that the super-generating stations have been designed upon a comprehensive or national basis, and I claim that it is equally important to consider the supply of heat upon a large scale. In many manufacturing localities the power load far exceeds the lighting load, but even in such cases many industries require heat in some form for boiling or drying purposes, apart from the heating of the factories.

Special arrangements would have to be made in such instances to supply the steam at a suitable pressure, and this service could be maintained by live steam for continuous processes when the power plant was not running.

Assuming, then, that there is a demand for the heat in the immediate neighbourhood of an existing generating station, the question arises: Can the existing plant be adapted to meet both services? It is, of course, quite clear that the utilization of the exhaust steam, even at a pressure of 2 lb. per sq. in., considerably reduces the electrical output, and would therefore involve putting into commission an additional unit or units, thereby increasing the actual consumption of fuel and adding to the total cost of production to maintain the electrical load and at the same time to supply the steam for heating purposes.

Against this added cost the income from the sale of heat would have to be set, and the revenue thus derived would also have to cover a reasonable return upon the capital outlay required for the distributing mains and ducts. This cost would vary according to the particular locality and the length of main necessary to include suitable buildings. The steam pressure also might have to be varied to meet special local conditions.

As I fully realize that no electrical engineer would welcome any suggestion which would so materially affect the electrical output of any unit and throw out of commission expensive condensing plant expressly designed to increase that output, I have already alluded to the difficulty of the adaptation of existing plant to meet both services.

If the super-station plan is generally adopted, it involves the scrapping not only of the generating plant but also of the boiler plant and, I understand, using the existing stations only as substations. If, on the other hand, the station remains as a heat distribution station, with a heat load approximately equal to the capacity of the boiler plant, then it involves only the discarding of the condensing plant, the electrical output becoming the by-product.

As in all probability the demand for electric current would continually increase, the extra boiler power and specially designed generating units could, if space permitted, be provided or the additional current could be supplied from the super-station. The station would then be constituted as a combined heating and electric supply station, with an income derived from both sources.

The important question then arises: Is such a scheme a practicable and a paying proposition? From an engineering point of view I say it is possible to provide suitable steam mains for the supply of heat and to extend such supply to a distance of, say, 1 mile from the station. There would, of course, be difficulties, but these could be surmounted.

The income to be derived from the sale of the heat depends upon the price charged for the steam supplied, and this should be calculated not only upon the actual cost at the station, but also on the cost of its distribution to the consumers, as this would vary according to the distance to which the supply was taken.

The price should be subject to any rise or fall in the cost of coal, on the basis of a fixed amount per 1 000 lb. of steam supplied for every 1s. variation in the price per ton of coal. It is only fair that the consumer should benefit by a fall in prices if the central authority has the right to increase the charge to meet any advance. I suggest that 4s. per 1 000 lb. of steam supplied would be a reasonable charge with coal costing £2 10s. per ton, and it would be to the advantage of the consumer to purchase the heat at this price, taking into consideration the high cost of fuel and labour. In addition to the saving in cost, a constant supply of heat with the minimum risk of breakdown is certainly an immense advantage.

The heat supplied would be measured by the amount of condensate, recording meters being fitted with every installation. This would apply in all cases where the condensate could be measured; if steam were supplied for other purposes than heating and hot water supply, it would be necessary to provide steam meters.

An Ideal Central Station.

From a heating engineer's point of view a central station should be designed to meet the requirements of the immediate neighbourhood, whether for industrial or domestic purposes. The three essential services are heat, light and power, and it can safely be assumed that, within ten or more defined districts, not even two would require the same proportion of these services. In a residential neighbourhood the heat load would be more constant, and included therewith would be the steam required for hot water supply. The maximum demand for this would occur in the morning, with a lower load in the afternoon and an increased load again during the evening.

This assumed heat load is indicated in Fig. 1 for a complete day of 24 hours. The dotted-line curve gives the approximate rate of electrical output from generators designed to meet the working conditions. The assumed lighting load indicates that at certain hours of the day there is a considerable surplus of electrical energy which is available for other purposes.

If a further demand of current for cooking purposes were added to the lighting load, it would probably show peak periods from, say, 8 a.m. to 8.45 a.m., and 11.30 a.m. to 1.30 p.m., and a further peak from, say, 6 p.m. to 8 p.m. The lighting plus cooking load is also shown, and it will be noted that the possible electrical output from the heating and hot water service loads covers the demand for lighting and cooking. This diagram (Fig. 1) shows an average winter load. If power is required in addition to the various services above the margin already referred to, it would be necessary to commission other generators to meet this demand, or to obtain the extra supply of current from the super-station.

It is necessary also to consider the requirements of the same district during the summer months. Fig. 2 also shows an assumed summer demand for hot water supply, lighting and cooking, and here it will be seen that the omission of the heating load makes a great difference, and proportionately also the electrical output is much less, so that, although the lighting load is so small, when the cooking demand is added thereto the peak periods are above the line of electrical output from the hot water supply. In other words, if electric cooking were used to the extent shown in the figures, there would be three periods per day when all the exhaust steam could not be utilized. It might be possible to provide some form of thermal storage to use the exhaust for these periods, if there were a large local demand for hot water.

Further, when the power load is added (and it must be assumed that such a load would be practically constant throughout the year) it shows the necessity of providing some condensing plant to deal economically with the extra electrical load, or to depend upon the power station or super-station for this supply. If no supply from a super-station were available, then,

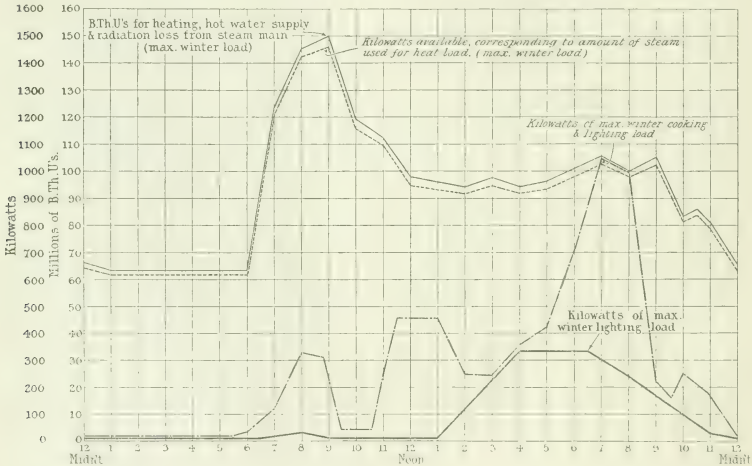
B.Th.U's for heating, hot water supply & radiation loss from steam main (max. winter load)
Kilowatts available, corresponding to amount of steam used for heat load. (max. winter load)
Kilowatts of max. winter cooking & lighting load
Kilowatts of max. winter lighting load
Kilowatts
Millions of B.Th.U's.
Midnt
Noon
Midnt

Fig. 1.

to meet all demands within the district, the plant would have to be designed with the proportion of condensers necessary for the load variations.

Some generating stations in London and in many cities and towns in the United Kingdom are extremely well situated for heat distribution, and I understand that under the scheme of the super-generating stations many of these would be shut down and the whole of the boiler and generating plant scrapped. It may be argued that the present plant in many instances is obsolete and uneconomical, and purely for the purpose of generating electric current this is doubtless true, but I claim that a large number of these stations with their existing boiler plant would serve excellently as heating stations, thus utilizing the boilers to the best advantage, in which case either a part of the generating plant could be altered to exhaust at a pressure up to 60 lb. per sq. in., or new plant could be specially designed to meet these conditions. I am aware that with buildings provided with existing installations for heating and hot water supply, and those of suitable size for the steam service. If a further proportion of new buildings were erected within this area, this load could easily be doubled.

Taking the above figure as the demand, this would require additional steam at the station to allow for radiation losses, thus making the figure, say, 165 000 lb. of steam. With a boiler pressure of 150 lb. and superheat of 100 degrees F., and with generating plant designed for a back pressure of 60 lb. per sq. in., the steam consumption would be at the rate of about 115 lb. per kilowatt-hour, so that it would be possible to obtain power at the rate of about 1 450 kW. Exhausting at 60 lb. per sq. in., there would still be some superheat in the steam, which would assist in reducing the radiation losses in the mains. The consumer would also benefit by any superheat remaining in the steam delivered to the calorifiers.

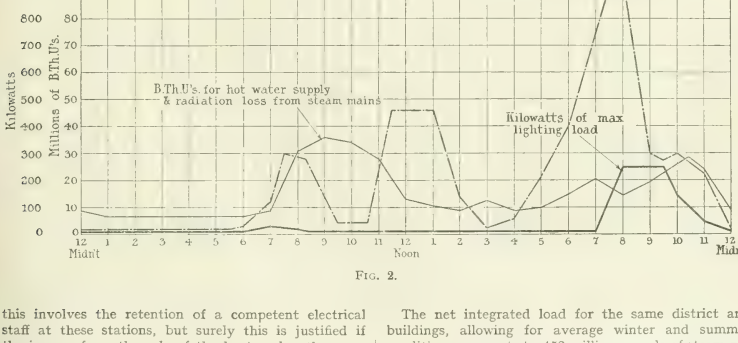

FIG. 2.

this involves the retention of a competent electrical staff at these stations, but surely this is justified if the income from the sale of the heat makes the combined station a profitable undertaking.

In some cases, especially in London, the difficulty of fuel delivery is given as a further reason for shutting down, but coal has to be delivered to every house or block of buildings in the district, and the need for this coal would be largely eliminated if a complete system were installed.

As these stations exist with their chimney shafts, no objection could be raised to their remaining, whereas if new heating stations were suggested in some similar positions, considerable opposition would have to be met. In my opinion, therefore, the advantages of retaining the existing stations where they are conveniently situated outweigh all the objections.

To take one example in London: a careful survey of the district within an approximate radius of half a mile from the generating station shows a possible heat load of 160 000 lb. of steam per hour, dealing only

The net integrated load for the same district and buildings, allowing for average winter and summer conditions, amounts to 452 million pounds of steam per annum. The gross income derived therefrom would amount to £90 400 if charged at the rate of 4s. per 1 000 lb., and the approximate number of electrical units obtained from the heat load to 3 930 000, which, at an average price of 2·2d. per unit, would amount to about £36 000.

The cost of the distributing mains, including all necessary work in the station and the formation of ducts, would depend upon the length of main required to serve the particular district, and the earning capacity of any main laid down would vary in like manner. Taking the same district, the total expenditure for engineers' work would be about £82 400, covering over 4 miles of streets, an average cost of £17 800 per mile, and an average earning capacity of £19 500 per mile.

The total load per mile is low, as one particular main a little over half a mile in length has an earning

capacity of £23 800, equal to £37 000 per mile, showing that in districts where large buildings line the streets the income per mile would be still larger.

In addition to the distribution of heat by steam mains, it is possible in some cases to use hot water with advantage. It enables the heater condensers to be situated at the central station, and, by reducing the back pressure to 10 lb. per sq. in. or less, the heat load would give a larger amount of electric current. Radiation losses would also be reduced, and all steam traps in the ducts would be eliminated. There are, however, other difficulties, principally that of metering the heat delivered; the quantity can easily be measured, but a variation of temperature would involve a loss to either the consumer or the supply company.

The sale could possibly be arranged upon a British thermal unit basis by metering the rate of supply and registering the temperature by recording thermometers, but this would involve expensive apparatus for every user, and additional clerical work in making out the accounts.

The water mains could be designed to meet the demands for heating and hot water supply, but if steam were required for cooking, e.g. boiling, sterilizing or drying, it would necessitate installing a steam boiler for such service in any building. The special needs of any neighbourhood would therefore have to be ascertained before deciding upon the system to be adopted.

In addition to the advantages derived by district heating in the saving of fuel and labour and the reduction of dust and dirt in the houses and buildings, there is the benefit to the district due to the reduction of smoke. The purity of the atmosphere of our cities and large towns during the coal strike was very marked, which proves that if the principle of heat distribution and the use of electricity or gas for cooking purposes were adopted on a large scale, the atmosphere would be very much purer and health conditions improved.

A complete scheme on these lines was worked out for dealing with 2 000 houses on one estate. The central station was to provide electric current for lighting and cooking, and a complete system of heating and hot water supply. Unfortunately, the scheme had to be stopped owing to difficulties of finance.

Ducts and Subways.

These introduce difficulties, owing to the congested state of the space below the roads and pavements. It is a costly matter to form subways, but there is no doubt that a large subway under all main thoroughfares would be an immense convenience. It is not uncommon to see a newly-made road cut up for attention to gas or water mains, or even the laying of new cables, and the annual cost to the various boroughs and companies must amount to a large sum.

By uniting all the services and accommodating them in one suitable subway, the cost to each service should not be prohibitive, and the proportion might be determined by capitalizing the expenditure incurred over a period of years for cutting up and making good the roadways, etc.

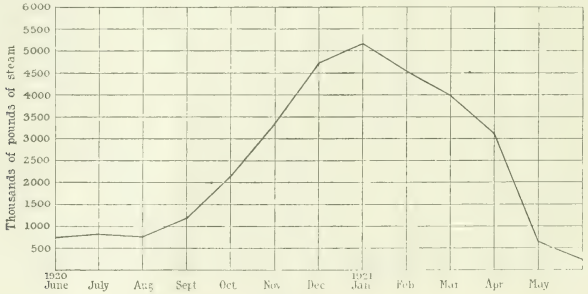

Fig. 3.

I shall now give a brief description of what has already been accomplished. In 1911 the firm with which I am connected was entrusted with the heating and ventilation of the new buildings (now known as St. James's Buildings) in Manchester for the Calico Printers' Association. Our work included complete boiler plant for a maximum load of 12 million B.Th.U.'s per hour. The back of the buildings abutted upon the Corporation generating station in Dickinson-street, and we proposed to the City Electrical Engineer, Mr. S. L. Pearce, C.B.E., that the Corporation should supply exhaust steam for heating the new buildings. Negotiations proceeded and a contract was entered into between the Corporation and the Association.

The adoption of the scheme obviated the necessity of building a large chimney, and thus gave added space on every floor, besides reducing the size of the heating chamber in the sub-basement. It also saved the construction of a coal conveyor from the canal into the basement, with consequent dust and dirt,

and the removal of ashes. In labour it saved the handling of approximately 800 tons per annum, and one man now looks after and controls the whole plant.

The condensate is measured by a Lea recorder, and electrically-driven pumps (in duplicate) return the whole of the condensate to the generating station.

Subsequently the scheme was extended to a distance of about 600 ft. from the station to the Refuge Assurance and other buildings. At the Refuge buildings new heating boilers were replaced by "calori-conomizers," and the coal bunkers were converted into strong rooms.

Even at this distance the back pressure at the station does not exceed $1\frac{1}{2}$ lb. per sq. in. The condensate is not returned from this building, but is filtered and used in connection with the hot water supply for the lavatories. Other buildings are now supplied with steam, and Fig. 3 shows a heat chart drawn up from information kindly supplied by the Corporation Electricity Department.

In conclusion I should like to say that I feel convinced that the co-operation of heating engineers with electrical engineers is the only satisfactory way of dealing with this important matter so as to produce economical, efficient and profitable results, and I hope that this first joint meeting of our Institutions may be followed by others dealing with subjects of mutual interest.

[An instalment of the discussion on this paper will be found on page 273.]

THE UTILIZATION OF WASTE HEAT FROM ELECTRICAL GENERATING STATIONS.

By F. H. Whysall, Member.

(*Paper received* 28*th December*, 1921; *read at a Joint Meeting of* The Institution *and* The Institution of Heating and Ventilating Engineers 19*th January, and before the* North-Western Centre, 21*st February*, 1922.)

Summary.

In the following opening remarks, I do not pretend to have gone very deeply into the subject, the object being merely to suggest points for discussion in the light of my own personal experience of the practical difficulties encountered in attempting to carry out any schemes such as those under discussion. It is hoped, therefore, that members will consider these remarks in the light of suggestions for the development of a useful discussion.

The majority of electrical engineers responsible for the operation of power stations for electricity supply deplore the fact that so much of the heat value of fuel is rejected to the condenser where steam is the source of energy for the prime mover. It has been suggested that special efforts should be made by supply authorities to surround their power stations with industries such as paper-making and sugar-refining, in order that they may sell their exhaust steam for use in industrial processes. Theoretically and thermally no fault can be found with this proposal, but it is when we come to the practical difficulties that doubts arise. In the first place, most of the undertakings with processes suitable for co-operation with this kind of power station are established in special districts and their positions are not convenient. I am of the opinion that in many cases this difficulty can be overcome, on account of the ease with which energy can be transmitted in the form of electricity from one place to another, and I suggest that the discussion of this subject should follow the lines of putting forward commercial terms for the co-operation of steam-using industries with the supply authority so that the two may mutually benefit; and, where steam is required for heating or industrial processes within a radius of $1\frac{1}{2}$ miles of an electric power station, how the steam can be supplied from the power station with benefit both to the power station and to the consumer of exhaust steam; the conditions under which this supply should be given, and the commercial arrangement necessary between the parties to ensure mutual satisfaction. The commercial arrangements are the most difficult part of these proposals and, after they have been settled by agreement on some generally accepted scale of charges, we may expect a very great saving in fuel.

With regard to the charges to be made for exhaust steam, I suggest that with coal at 10s. the proper charge would be 10d. per 1 000 lb. where the condensate is recovered by the supply authority and the distance is not more than 1 mile from the power station.

For the supply of electrical energy as a by-product from an industrial works making a large use of steam, in order to make the arrangement a success it is necessary to allow the supply to be given when available, and this is equivalent to providing the waste-heat plant with a load factor of 100 per cent. The proper charge I would

suggest for a supply of this kind is 0·1d. less than the fuel cost of the supply authority for this load factor.

It is very difficult indeed to fix a scale which will with certainty divide the profits between the parties. I have had experience of arranging contracts both for the supply of exhaust steam from the power station and for the use of process steam for generating electricity at an industrial works for general supply; and the chief point to bear in mind in working out the details of any proposal is that the benefits should be equally divided between the parties under all the varying conditions likely to obtain in actual practice. It is easy to obtain this end, where the two concerns belong to one authority, by the isolation of accounts in connection with the scheme, or, in the case of a combination of industrial concerns under one ownership, by forming a subsidiary company.

With regard to the supply of exhaust steam from an electric power station for heating purposes, each case must be considered on its merits. The heat available for transformation into electric energy depends upon the temperature limits and, if the lower limit is raised to serve another purpose, the economy of generation must suffer accordingly. It is necessary to regard electrical energy as a by-product in this case and, in order to get the most economical results, the back pressure must be kept as low as possible, a maximum of 2 lb. (gauge pressure) being aimed at as a practical possibility. This means that the exhaust-steam supply pipes and the calorifiers for the heating systems must be of such dimensions that this pressure should not be exceeded. In agreements for supply, a back pressure of $\frac{1}{2}$ lb. per square inch at consumers' premises should be specified, as I consider this to be a quite reasonable requirement. The engine unit used must be of a size suited to supply the exhaust steam required for heating purposes when working under full-load conditions.

The friction load of a 750-kW set is often equivalent to 5 000 lb. of steam per hour, and it is a very large building that will take more than this quantity. It is seen, therefore, that unless the 100 per cent electrical load factor can be given to the set or sets used, there is very little profit on the arrangement. Where the heating load is small, an alternative is to "bleed" a turbine or to take off a supply from the receiver between the cylinders of a compound reciprocating engine, the remainder of the steam going to the condenser in each case. It is doubtful, however, in these cases if the electrical energy is generated more cheaply than it would be by a large modern electricity generating station using 11 to 12 lb. per kWh, and the fact that the provision of a load factor of 100 per cent to the plant supplying exhaust steam for heating purposes is effected at the expense of the load factor at the main power station, must be taken into consideration when comparing results.

There is also the financial difficulty in connection with expenditure on the steam-distributing mains. Electricity undertakings have no borrowing power for such a purpose and the expenditure is necessarily a charge on revenue account, and in the most likely areas for a supply for heating purposes the streets are already so congested with gas and water mains, sewers, and electric cables, that it is a difficult matter to find room for steam mains which need to be of special design in order to prevent excessive radiation losses. It has been found, however, that these difficulties can be overcome by an enthusiastic engineer, and wayleaves can be found most readily through the basement premises of buildings *en route*, the proprietors of these premises being induced in most cases to take a supply. The supply of exhaust steam for heating purposes is invariably most satisfactory to the consumer and the demand is generally ahead of the facilities for supply.

It is said that combined stations in America have been abandoned in many cases in favour of a separate central station for the supply of steam for heating purposes only, but this does not necessarily prove that there are not many cases where a properly organized system of collaboration between existing electric supply stations and heating consumers in congested city areas should not be profitable to both parties. It is my opinion that electric supply authorities cannot afford to ignore the demand for exhaust steam or the possibility of obtaining cheaper supplies of surplus energy from generating stations established in works using low-pressure steam for industrial purposes, and every endeavour should be made by central station engineers to make collaboration a commercial success.

[An instalment of the discussion on this paper will be found on page 273.]

DISCUSSION ON

"THE UTILIZATION OF WASTE HEAT FROM ELECTRICAL GENERATING STATIONS."

At a Joint Meeting of The Institution and The Institution of Heating and Ventilating Engineers, 19 January, 1922.

The discussion was opened with the following introductory papers:—

"Utilization of Exhaust Steam from Electric Generating Stations, and Coal Economy," by **C. I. Haden**, Past President of the Institution of Heating and Ventilating Engineers (see page 265); and

"The Utilization of Waste Heat from Electrical Generating Stations," by **F. H. Whysall**, Member (see page 271).

Colonel R. E. Crompton: As my work for many years past has been chiefly in economically distributing electrical energy, I have naturally studied the question whether we could not with advantage also become distributors of heat energy, following the example of American engineers. Apart from the question whether our existing powers enable us to do this, there can be little doubt that it would be best to follow the more recent American practice at some of our central stations built originally as generating stations, to utilize the boiler plant by distributing therefrom heat energy in the form of highly superheated steam at considerable pressure. In this way the heavy losses and large pipes necessary for utilizing the heat energy in the exhaust of generating steam plant could be avoided and, in my opinion, success lies in this direction. As an electrical engineer I wish to say that I do not for one moment think that heat distribution can be carried out by any one method. There is no doubt that distributing engineers have had their eyes opened during the past year or so to the certainty of a great increase in the demand for electric heating and cooking, and this arises from two causes, first the great increase in the cost of fuel, and secondly the high cost of domestic service. In the past much of our servants' time was occupied not only in laying and making up domestic fires but in dusting and other cleaning work which follows from the use of the domestic grate, so that now when everyone has been compelled to cut down their wage-bill they find that if they use the electric radiators properly they do not grudge the present price for heating by electric radiators the smaller class of rooms, whether they be offices, living rooms or bedrooms. The chief feature in using electrical heating is in what I might call its "convenience factor." Although it is true, as the authors have pointed out, that the heat units from electric heating as compared with the original heating energy in the coal may be as low as only 5 per cent, yet when such high-class energy is brought very close to the point where it is required, e.g. by the sick man's bedside, or, in the case of an aviator, in the aeroplane by applying the heating current directly to his clothes, it will be found that of this high-class energy 96 per cent is available as radiant heat very close to the point to be heated. On the other hand, the real efficiency of the ordinary heating by radiation from an open fire or by convection currents of heated air from central heaters is so low that whether we burn the coal as well as we can in the best form of grate or whether we use central furnaces and heat by hot water or by steam radiators, in all cases we are compelled to warm up the walls of the rooms and the result is extremely wasteful as compared with the efficiency that we get from an electric radiator placed near us and radiating direct on to our bodies. The British public would not pay the large sums that they are now paying for electric heating if they did not find it to their advantage to do so. They are beginning to appreciate what can be done by direct radiation or electric heaters, and I feel certain that this practice will extend and that it will greatly affect the electric demand from our lighting and power stations. I find that a good many of the most efficient electrical radiators are of foreign make. In France particularly they appear to have studied this matter.

Mr. F. Biggin: A good many of the points made by Colonel Crompton with reference to the advantages of heating by electrical appliances might just as truly have been applied to heating by steam or hot water. The point under discussion, however, is the utilization of exhaust steam from generating stations. I think most of those present to-night realize the value of exhaust steam. Heating engineers do not claim the monopoly of desiring to make the best use of it. It has been pointed out that a very great waste of thermal efficiency has resulted in endeavouring to get the best electrical efficiency from generating plants. It is this loss which we wish to arrest and we consider it is more practical, wherever there is a possible use for exhaust steam, to make thermal efficiency the first object. At the Imperial College of Science the exhaust steam from the generating station is taken to the buildings surrounding the Imperial College of Science. The Royal School of Mines, the Royal College of Science, the Natural History Museum, and the Albert and Victoria Museum, are all heated from one centre. As practical men I think we should thoroughly consider the better utilization of waste of any kind. The world just now calls for economy, and anything that can bring about economy should be very carefully considered. I sincerely hope that, after the discussion to-night, it will be considered desirable to set up a Joint Committee to discuss this subject further and to report to another joint Meeting.

Mr. W. H. Patchell: Forty years ago Mr. B. Holly at Lockport, N.Y., started steam-heating his own house. His neighbours were supplied, and the pipes were eventually laid down for 3 or 4 miles. Then

matters changed, and steam-heating plants in America were run on exhaust steam. Another change was made and they have now gone back to direct steam. I am reminded of the discussion on Sir Dugald Clerk's paper at the Royal Society of Arts after the super-station scheme was launched. I suggested that if thermal units were the currency of the country these thermal matters would bear a very different aspect. We have to live on a paper currency, but these changes in values will very probably put a different aspect on this question of heating. The question is: Does the present method pay? Up to the present we have found it does pay. In Manchester, steam is taken from the central power station to neighbours and used, as Mr. Haden says, very beneficially. I know a case in which enthusiastic vendors of electricity persuaded people to shut down a private plant. The amount of coal used on that private plant for heating was so great that the coal bill of the consumer has been very little altered and he has had in addition a considerable bill for electricity, which proves that the matter must be studied from both sides. Large blocks of business premises generally want more heat than they do light or power—I am not speaking of manufacturing premises—and there obviously electricity would be the by-product. Colonel Crompton spoke of losses. Steam-heating companies are running with 83 per cent of the steam which leaves the station sold and paid for. This compares very favourably with the results obtained by many electric supply authorities. In 1903 there was a little station "up town" in the residential part of Detroit, Mich., where there were two 500-kW machines, the exhaust steam from which, at about 5 lb. back pressure, was used for steam heating. That plant was taken over by the Detroit Edison Company, who in 1904 built a station "down town" at Farmer Street. Here the boilers were run at high pressure with high-pressure steam feeders, and a low-pressure distribution at 15 lb. to consumers. A central heating company also had a plant "down town" from which they supplied the exhaust of a turbine. That plant was taken over eventually by the Edison Company, who in 1912 started another steam-heating station "down town" at Park Place. In 1914 this company took over the whole of the steam-heating business in Detroit and started a big central-heating station in Congress-street, in the centre of the "down town" area. That station is equipped with boilers which operate at 125 lb. pressure. The steam is sent out through high-pressure feeders and delivered to the consumers at anything from 30 lb. to 15 lb. The guaranteed pressure to the consumer is 10 lb. Any lower pressure is useless for cooking. At Congress-street they put into operation in December last the largest boiler in existence and that boiler is running on direct steam supply. This confirms Mr. Whysall's statement that exhaust steam has been abandoned in some stations. Mains 12 inches in diameter covered with $1\frac{1}{2}$ inches of insulation are laid in the street; then comes a wood form and outside this a concrete envelope. Many of those pipes have been in service since 1909. I saw some of them 14 months ago and they were then as good as new. In some districts leaky water pipes have rotted the wood outside, but generally the wood is quite good. For many years, however, the use of wood has been abandoned and concrete only used. The difficulties engineers have had to face in Detroit are what we should have to deal with in London. A tunnel 8 ft. wide, 8 ft. high, from 25 to 40 ft. underground and some 2 miles long, is used for steam pipes only, and the capital cost is thus enormously increased. I am indebted to Mr. J. H. Walker for the above information regarding Detroit, which I obtained partly from him personally during my visit to that city and partly from a paper on "Central Station Heating in Detroit," which he read before the American Society of Mechanical Engineers.

Mr. A. H. Barker: The use of heat by the general public varies very greatly indeed. At the present time I am making experiments on the amount of heat used by the working-class population in three cottages which the London County Council have placed at my disposal for the purpose. Though the experiments are only in their initial stages I have already obtained figures which show that 80 000 B.Th.U.'s per day supplied in the form of gas will serve all the requirements of a whole house of 4 or 5 rooms occupied by two ordinary working-class people in cold weather, when no restraint but ordinary care is placed on its use. Obviously such figures must depend very greatly on the way the house is used. Although I have separate figures for the hot water supply, cooking and heating, I have not yet any figures for the summer season. But even taking this amount as an average for the year, which it certainly would not be, this gives us 29 200 000 B.Th.U.'s per annum, which, at 1s. per therm, shows that a cottage of this kind could be supplied with gas throughout the year for a matter of perhaps £10 or £12. Now gas is a relatively expensive form of heat. I shall continue the observations on the same cottages, in the same occupation, with solid fuel of various kinds. The figures I have are therefore admittedly incomplete as yet. But we have shown in our laboratory that the cost of solid fuel is about half the working cost of gas. I have no doubt whatever, therefore, that for the sum of £6 a working-class family could supply all its requirements as to heat without any difficult or undue restrictions. Now if we were supplying heat from one or more pairs of mains in the street, whatever may be at the other or business end of the main, we should certainly use more than this. Does anyone suppose that we could give a working man all his heat for a year, including the interest and depreciation on the capital outlay, maintenance, supervision, and the multitudinous other factors that would enter into the cost, for the sum of £6, or that in any case the working man would accept his heat in the form of radiators and constant hot water? Even so, how is his wife to do her cooking? Apart from that, he will have to be given his fire, either coal or gas, in addition. On account of the possibility of breakdown it would be necessary to duplicate the plant. It would be necessary to have gas as well as steam mains, and, it is hoped, electrical mains. How are we to do this on £6 a year? What will the subways, the coating,

the expansion bends, the steam traps, the pumps and heaters cost? Is it to be expected that a plant could be put down to serve, say, 1 000 cottages for less than, say, £100 000? The total amount received to cover running and commercial costs will be £6 000 a year. Financially, therefore, the general idea of supplying small houses from a centre seems to me impossible. The case is different where there are groups of large buildings in close proximity to electric light stations, but the number of such groups is very small. The true solution of the problem of centralization is, in my view, very different. What are the exact facts? Just as the community needs a supply of money which it can at once convert into labour, or any kind of commodity, so it needs a supply of energy with all the impurities filtered off, such as soot, ashes, and the like, which it could instantly turn into any other form of energy, e.g. light, heat or motive power. Electrical engineers undertake to manufacture it from the raw material, coal. In the present state of their knowledge they cannot manufacture it without wasting 90 per cent of the raw material. We as heating engineers are invited to do the best we can with this waste heat, whereas what should be done is to reduce its quantity to as great an extent as possible. The only solution that I can see for any practicable scheme of centralization is for the electrical engineer, the mechanical engineer, the gas engineer, the physicist, the chemist and the heating engineer, to co-operate to see if they can devise some way of manufacturing electrical energy with less than 90 per cent waste. It must be remembered that gas engineers can put into their mains 80 per cent of the energy of the coal Even so they are obliged to make gas so expensive that the working man cannot really afford to use it. If the electrical engineer could approach that figure nothing but electrical heat, light or power would be used in the world. Until then, however, I fear that schemes for patching up electrical methods are foredoomed to failure because the financial outlook is impossible.

Mr. J. F. Raggett: Colonel Crompton has suggested that it may be best to utilize electricity for heating in combination with steam or hot water. In addition to the advantages which he has mentioned, it is likely that this arrangement would often assist in maintaining a better balance between the electrical and steam demands. Mr. Barker considers that it cannot possibly pay to adopt central heating for small dwelling houses, seeing that these spend only about £7 per annum for coal, and that central heating would involve heavy interest and depreciation charges. In this connection, the present system of heating by open fires is by no means convenient; it involves a deal of wearisome labour, also dust and dirt. If a convenient method were adopted, on the lines of the system now under discussion, we should doubtless take advantage of it and have our homes more uniformly and comfortably warmed. It is indeed gratifying and encouraging to know that this subject of waste-heat utilization is now receiving the attention which it so justly deserves. I should like to say a few words with regard to the question of the suitability of existing power plant for the purpose under discussion. Presumably, most of these plants are reciprocating engines, which is fortunate, as a steam turbine, unless specially designed, is not well adapted for exhausting against a back pressure, and even when specially designed as a pure back-pressure turbine will not give such a large output under these conditions, with a definite quantity and quality of steam supply, as a reciprocating engine. The turbine is essentially a condensing unit. The majority of the engines in power stations are either compound or triple-expansion sets. If these engines were set to work as they stand, to exhaust at an unduly high pressure, they would be liable to operate in a very laboured fashion due to excessive expansion which results in negative work. This may indeed be present to such an extent as to cut out the low-pressure line entirely as regards its usefulness, making it a drag on the high-pressure and low-pressure lines. With combined power and heating, there are several considerations which favour a low exhaust pressure. Let us, however, first consider a high pressure, as this may occasionally be required under the proposed system. It is quite possible to use a high pressure with a suitable engine, and I know of many industrial plants exhausting at all pressures from 15 inches vacuum up to 60 lb. gauge pressure. Indeed, in one special case which has proved very satisfactory, a 650-b.h.p. engine takes its steam supply at 250 lb. and exhausts at 190 lb. to a carbonizing process. Any surplus steam at 190 lb. is utilized by a 430-b.h.p. engine exhausting at 35 lb. to another process. Doubtless, if a high pressure were really necessary for heating and hot water service in some instances, certain designs of existing engines could be converted to non-compound, which is the correct type for this condition. Coming now to lower pressures, existing compound engines, at any rate of the high-speed type, may often be arranged to exhaust up to 25 lb. gauge pressure without extensive modification, and assuming an ordinary steam pressure for existing stations of, say, 150 to 180 lb. It is a question to what extent a back pressure may be satisfactorily applied to a triple-expansion engine, though this type is called upon to exhaust to atmosphere occasionally, and is also satisfactory when exhausting to a turbine at from 2 to 5 lb. back pressure, possibly after some modification to the valve setting. Seeing that pressures varying from a low vacuum to, say, 5 lb. gauge are often found suitable for heating buildings and hot-water supply, heating engineers will doubtless be able to give due consideration to the suitability of the engines when deciding upon the exhaust pressure to adopt. I could mention many cases of substantial saving by the adoption of combined power and heating in works and institutions. In one such instance a saving of £9 000 per annum has been reported, while another example relates to a large chemical works where the saving amounts to £20 000 per annum. In view of what has already been accomplished, surely there are no insurmountable difficulties in extending the scope of operations to the heating of districts from conveniently situated combined power and heating stations. Moreover, a number of model

villages will probably come into existence during the next few years which will offer ideal conditions and opportunities for the installation of a combined power, lighting and heating plant. In conclusion, it is obvious that if we are to maintain our position as a progressive nation, we cannot afford to perpetuate a system which wastes 60 per cent of the heat supplied, without fully investigating the claims of the proposals now under discussion, which, judging by the results already obtained, show promise of a great saving in our national asset, coal, in addition to numerous incidental advantages.

Mr. W. M. Selvey : The author used the expression " pure energy." I will not say I have invented, but I have used in my writings, something a little different, in that I have tried to imagine that mankind needs two kinds of energy which I have termed " high grade " and " low grade." What Colonel Crompton from my point of view said was this, that if mankind is provided with high-grade energy he can always degrade it into low-grade energy at his will in the most convenient manner; and that pure-grade energy reaches its optimum, as has been said, in the electrical form. For many purposes mankind needs not heat but temperature. I think Mr. Barker was perhaps a little incorrect in his reference to a scrap-heap if he considers that every heat engine works essentially in itself by rejecting heat at the lower limit. That is not exactly a scrap-heap in the sense of material for which we have no use. It is a different part of a definite process of getting pure energy. We are faced with two alternatives, i.e. whether it is more profitable in the long run to concentrate wholly and solely on getting the largest amount of high-grade or pure energy from the rough raw material, or to devise processes whereby, in the process of getting pure energy, the remainder is left in such a form as to be useful for a good many of the needs of man. That is a very big question. Dr. Ferranti once said that if one concentrated on getting pure energy in a sufficiently commercial form, so that it could be used for all purposes, then there would be no other question left for solution. That has already been said by another speaker in a different form, viz. that high-grade energy is so adaptable in its pure form and can be applied so conveniently that we need not consider any other form. In other words, if we are warm we need not concern ourselves about warming other things. For industrial purposes, however, experience has shown that it is commercial so to obtain the pure part of the energy that the greater part of the remaining energy can be profitably left in a form which is useful to mankind. Generally speaking, most of our processes which deal with organic matters, or a great many of them at any rate, do not require temperatures much higher than 200° F. or 240° F., i.e. not much above that of boiling water, because above those temperatures nearly all such substances break down and become chemically dissociated. Therefore, in all the work which we do in providing organic materials worked up in a form useful for mankind, we undoubtedly require very large quantities of what may be termed low-grade energy. It follows that there are very many practical processes typified by what we know as " bleeder " turbines, and there will always be a great field for that class of work. Then there are the questions of food, washing, and the warming of buildings. Washing is a very big question. I was very much struck by Mr. Barker's remarks as to what the housewife could do if she were able to turn on a tap and use as much water as she wished. The sum total of water used per head for all purposes is of the order of 30 gallons per day, a small amount compared with what would be used if unlimited hot water were available to all. On the other hand, the provision of this quantity per day amounts in the aggregate to very large quantities, and any considerable increase would be a matter of concern to water engineers. I am afraid that the application of hot-water heating, although I have looked on it very favourably, must to some extent be built up on a gradual local application in special cases. In conclusion I should like to touch on the question which Mr. Barker mentioned, i.e. whether the electrical engineer is properly devoting his attention to getting a high proportion of pure energy out of his coal. He gives a valuable list of friends who will help us, but if their ideas of what we are doing are limited to the figures which are given very fairly in Mr. Haden's paper, I think electrical engineers ought to encourage them somewhat on the question of thermal efficiency. I was rather disappointed that Mr. Whysall did not do that, because the 10 per cent on his heat-balance diagram is not by any means the ideal we are trying to attain. Up to the present we have had to do the best we can, but the whole idea of the super-station is that that figure of 10 per cent will at once be increased to 20 per cent. That is an enormous difference, but 20 per cent does not represent the limit. We already have in sight a station which we hope will realize an efficiency of 25 per cent, and the mercury turbine, if it comes to a successful issue, may reach an efficiency of 30 per cent.

Mr. W. W. Nobbs: Owing to the limited time for discussion, I shall adopt Mr. Whysall's suggestion and pass over the theoretical and thermal considerations of this subject. Up to the present the largest business in district heating has been done in America. The first plant, serving some 3 miles of streets, was put into commission over 40 years ago, and to-day there are over 350 district heating companies comprising one of the most important industries in the United States. Mr. Whysall states that electricity undertakings have no borrowing power for such purposes as district heating. Granting this, and having regard to the rapid development of their own generating plants, it is somewhat surprising that the competent electrical authorities, while deploring the low thermal efficiency of their stations, should not have made a serious investigation into the possibilities of this large field with its promises of a greatly increased overall efficiency and a regular source of income. Many of the early district heating plants in America are still running, and on their records is founded much of the adverse criticism which has led to the impression in England that district heating cannot be made a financially sound proposition. To my mind criticisms based on such records are worthy of just as much

consideration as would be given to the running costs of a small electricity generating station even 20 years old, when considering the efficiency of a projected modern plant. The Secretary of the National District Heating Association of America told me that an article by Mr. Custer, which has achieved some notoriety in the American Press, was founded on an old water-heating plant that would bear no comparison with a modern installation of to-day. I view with some alarm the optimistic tone in which Mr. Whysall suggests 10d. per 1 000 lb. as the proper price for steam with coal at 10s. per ton. I cannot too strongly urge caution, and a thorough analysis of the capital and running costs before fixing a rate. The great difficulties that the American companies are now meeting are the outcome of fixing too low a rate in the first instance. These early rates were fixed by the Commissioners when very little was known as to the economic life of plant and mains. Again, many boiler plants having a test efficiency approaching 80 per cent prove to have an overall efficiency of only about 50 per cent, when taking into consideration banked fires and such losses all the year round. It is obviously an inducement to business if a prospective client can be shown that he will save money by using a commodity, and it is a point not to be lost sight of, but I suggest that the prime consideration in determining the price is the market value, or what it will fetch, rather than fixing the selling price on the lowest possible estimated margin of profit. Electricity has displaced oil lamps for lighting, although the latter are less costly, and in the same way one might logically expect that users of heat would be willing to pay more for the convenience and saving of trouble obtainable by a source of heat "on tap" as compared with independent apparatus in each building. In a recent bulletin the National District Heating Association give the heating rates for the 1921-22 season for the different companies throughout the United States. Where steam is the source of heat most of the companies have a sliding scale by which the price drops as the rate of steam consumption rises. The rates vary in different parts of the country from approximately $1.5 to $0.75 per 1 000 lb for the first 10 000 lb. of steam condensed per month. Below is given a typical scale showing the pre-war and present-day charges..

Cost per 1 000 *lb. Condensation.*

	1921-22	1914
	$	$
First 10 000 lb. condensation per month	1.10	0.85
Next 10 000 lb. ,, ,, ,,	1.00	0.75
,, 10 000 lb. ,, ,, ,,	0.90	0.65
,, 20 000 lb. ,, ,, ,,	0.85	0.60
,, 20 000 lb. ,, ,, ,,	0.80	0.55
,, 30 000 lb. ,, ,, ,,	0.75	0.50
Over 100 000 lb. ,, ,, ,,	0.70	0.45

In addition to these prices there is usually a fixed charge of about $2.5 per month for meter and service connection, such charge representing the interest on the capital value on the cost of the meter, maintenance and repairs and meter-man's wages. Where a forced hot-water circulation is the source of heat, it is usual to base the charges either on a seasonal flat rate per square foot of heating surface installed, or on the estimated heat loss of the building as calculated on a standard set of heat loss coefficients, but the tendency, even with hot water systems, is towards the more precise method of metering. The flat-rate scale of charges for 1921-22 varies in different parts of the United States from 65 to 40 cents per square foot of hot water radiation, while steam-heated radiation is calculated at approximately 25 per cent more. These American public utility companies render their accounts monthly, and they advertise 5 per cent and even 10 per cent discounts for cash, which is a somewhat different procedure from the "demand" note one receives from water companies in this country. The cost of coal is a very important factor, but not the only one to be considered in determining the cost of supply. In addition to the coal bill there are water, labour, interest, taxes and insurance, depreciation, maintenance, overhead and distribution costs. Consequently it would be wrong to fix a scale in which the charge is directly proportional to the cost of fuel. Where the turnover of a company is fairly regular it is a simple matter to regard the coal item as a variable and the remainder of the costs as a fixed charge, and to proportion the rates accordingly, and it seems to me that the right procedure for a new company would be to budget for a minimum amount of business and adopt the same procedure. A typical example may be cited from Ohio where there is a coal clause to the effect that: "the price upon which the rates are fixed is based on an average price of $3.50 per ton of bituminous coal delivered alongside the power station." The clause goes on to state: "If the average price per ton is higher or lower than $3.50 per ton, then for each and every 10-cent increase or decrease in such average price the base rates specified shall be increased or decreased respectively in the case of a flat rate by seven-tenths of 1 per cent per sq. ft. of direct air radiating surface per season, and in the case of meter rate by 1 cent for each 1 000 lb. of condensation." I give below the leading figures for a month's working of a district heating station, the point of interest being that in a station consuming 12 million lb. of coal per month, generating over $\frac{1}{2}$ million kWh, supplying nearly 1 million lb. of steam, and over 70 000 million B.Th.U.'s for forced hot-water circulation, the overall thermal efficiency was 49·6 per cent.

Coal consumed, lb.	12 030 500
B.Th.U.'s per lb.	12 510
B.Th.U.'s input to stations	150 574 millions
Total outgoing water, lb.	2 824 620 500
Average temperature-rise, degs. F...	25·2
B.Th.U.'s to outgoing water ..	71 214 millions
Steam to one consumer, lb.	873 970
B.Th.U.'s to one consumer	947·5 millions
Electric power generated, kWh ..	541 440
B.Th.U.'s to electric generation ..	1 850 millions

Total outgoing pumpage, lb. of water	2 824 620 500
Average pressure-head pumped against, ft.	158·7
Work done in pumping, ft. lb. ..	448 250 000 000
Work done in pumping, B.Th.U.'s ..	575·8 millions
Total output all stations, B.Th.U.'s	74 587·3 millions
Total input all stations, B.Th.U.'s ..	150 574 millions
Per cent overall efficiency	49·6

Mr. J. F. Driver: In the early days the "electricity station" was literally a central station, but nowadays the "electricity central station" is central in name only. In view of the fact that, at present, electrical engineers waste more than half the heat available from the coal, I feel that the time will come when we shall go back to the old arrangement and have a "central" station. The worst point about the present method is that it actually costs money to waste the heat. I want to suggest that electrical engineers should make a living by selling by-products. Years ago the gas companies made coal gas, but no gas company that did not sell its by-products could exist to-day. In fact, a gas company becomes to a very large extent a chemical firm, and with electricity it seems to me that it would be quite reasonable for an electricity supply company or a municipality to run auxiliary plant with a view to utilizing their waste heat. It is a case either of doing that or of putting the electricity station in such a position that it is convenient for other suppliers. It seems to me to be unfortunate that when we considered the question of super-power stations the question of arranging suitable sites surrounding other manufacturing concerns should not have been brought forward. Also, in our housing schemes surely it would have been desirable to make more arrangements for heating and thereby utilize the waste heat or steam. At Gorton, near Manchester, a large district is being heated by steam, and surely what can be done in one place can be done in others. It is very interesting to consider the possibility of new districts springing up and taking a heat supply from a conveniently-situated electricity supply station. The question of the cost of steam-heating in houses is always brought forward, but the people who make that criticism never seem to realize that the cost in an ordinary house for the hot-water apparatus is in itself considerable, particularly as regards the domestic water, which is heated very inefficiently by the kitchen fire. I would also point out that a very large percentage of houses have a fire in the kitchen or in the basement in the summer simply for giving a supply of hot water in the house. In the case of manufacturing companies, such as chemical firms, dye works and the like, I do not think the electricity authority can ever compete with the firm itself. I believe that if a firm will put down plant in the right way and utilize the exhaust steam, they will make electricity at a price that no municipality or super-power station could approach. Some little time ago I went into this question in connection with the electricity supply for Loughborough College. This College is comparable with a factory, in that it has workshop accommodation for over 600 students, a laundry, a bakery and various other departments. The cost at the present time of the coal and gas for heating purposes is £1 600 a year, whilst the electricity bill is £3 700 a year, making a total of £5 300 per annum. With a suitable generating station exhausting at 1 lb. per sq. in. pressure, it would appear, on paper, that a saving of no less than £4 700 per annum could be effected, the cost of labour being practically the same, because at present there are 8 boilers requiring attention, which are used simply for heating; a suitable power station would supply about 10 million B.Th.U.'s, which would be more than sufficient. It seems to me that electrical engineers could well consider the question of persuading manufacturing firms to purchase plant designed for use in conjunction with calorifiers, so that they could generate their own electricity and make their own heat. If it is a works where the heat demand is small, they would have to condense their steam in the summer, but many manufacturing firms would use their heat practically throughout the year. I should like to raise one other point, i.e. the question of the supply of heat to rows of shops. I think that electricity supply stations should consider the question of passing mains right through a long row of shops; this could be done very cheaply apart from the question of the cost of wayleaves.

Mr. W. N. Haden: I suppose the ideal central municipal station would be one which would include the generation of electricity, gas and heat, combined with a destructor plant, so that all these municipal services might be concentrated at one suitable point. The whole of the fuel might possibly then be carbonized before being used, and the by-products obtained. I mention a destructor plant, as in one fairly large town the whole of the tramway service is run from the destructor plant during certain hours of the day without any coal being used, and in one small town the day load of the electric light station is run from a destructor, thus showing that full use of this source of waste is not being made in the country generally at the present time. In another installation now being erected the hot water supply for some 580 houses is being provided from a destructor. With such a central station there would be an engineer-in-chief, with departmental engineers for each particular service. The engineer-in-chief would then be in a position to decide which department could most economically supply the needs of the customers, and whether these should be met by gas, electricity or steam. Another advantage derived from such a station would be that the mains of the various services would radiate from the same point, and this would justify expense in the formation of subways and reduce the cost of the same over that where a number of subways come from different points for individual services. Mr. Whysall's paper refers to the co-operation between electric supply departments and industrial undertakings, and the economy that might be obtained by supplying steam from the central station, where heat is required as well as light and power; also in the case of industrial buildings where a large amount of steam or heat and comparatively little power is required, in which case the current might be generated as a by-product and taken by the

electric supply department as and when it might be produced. This might be an advantage to both parties, and the more such undertakings are linked up the better probably will be the diversity factor, as the peak loads of the various undertakings might not synchronize. In one scheme for a garden city, where heating, hot water service and electricity were to be supplied from a central station, the curves of peak loads showed that it would be to the advantage of the city electric supply station to be coupled up with the station supplying the garden city, as the peak load of the demand for current at the latter would have come at a time when there was less load on the city station. The question of the future demand for the supply of heat has been raised. I believe that this demand will develop more rapidly than perhaps some may expect, and that owners when they find they have the facilities offered them will be glad to accept such facilities, so as to dispense with their own boilers and the concomitant cost of stoking, and the inconvenience of coaling and removal of ashes. There is also the question of public health, as affected by the atmosphere. It is worthy of note that in Glasgow during the coal strike there was a marked decline in the death rate, which can be attributed only to the clearer atmosphere. Anyone comparing the atmosphere of London on what we should term a heavy day with that of New York, where no soft coal is allowed to be burned in open fires, must appreciate the difference. The demand for heat in this country, where heating engineers calculate on the difference in external and internal temperatures of 30° F. and 60° F., as compared with America, where the figures are 0° F. and 70° F., would indicate that the heating factor is not so large in this country as in the Northern States of America, where heating is the largest of the three demands, viz. power, light and heat, and is often the determining factor in a central plant. Mr. Barker has mentioned the minimum number of B.Th.U.'s required for human existence in this country, but I do not think that anyone would be satisfied with such minimum if he were able to obtain more. Our experience of the rationing of food during the war has not made us anxious to live in future on the minimum amount of food which would enable us to exist. Station engineers have raised the question of the extra capital cost of plant if generating sets are provided suitable for exhausting when required at a back pressure; but this cost could be reduced if such portion of the generating plant, the exhaust steam from which would meet the minimum demand for heat, were provided in the form of, say, a high-pressure turbine without the low-pressure section or condensers. Such high-pressure end of a turbine would, of course, be the less expensive part of a set. In this country high charges are often demanded by electricity departments for stand-by services for summer use, whereas in America current is willingly supplied in the summer to those buildings which generate their own current in the winter in connection with their heating systems, as it gives a better load to the electricity department during the summer, when their load is lighter, thereby enabling them to use their plant to better advantage. The heating business is increasing rapidly in America. There are some 336 towns with their own district heating, and there were some 30 plants laid down last year. Most of the heating plants are now operated in connection with electric supply stations. If such combined stations are to be developed in this country, care must be taken that only such as are suitably situated or designed are undertaken. The individual circumstances of each case must be investigated in regard to the load which might be anticipated and the district over which it would have to be distributed. If these circumstances are not taken into consideration the result would not be satisfactory financially, and would tend to hinder the whole work.

Mr. W. H. Allen (*communicated*): I look upon the subject of the discussion as being rather limited to the utilization of the heat which is at present rejected to the condensing water in power plants, and not to any other form of rejected heat. After being 12 years in charge of an ordinary central station I joined a large group of works in which the combined system of power generation and utilization of exhaust steam was in use, and I approached that system with considerable prejudice. I have to admit, however, that in a very short time I was convinced that it was economically sound and that whatever little difficulties existed in supply and operation could and would be overcome. That holds so far as private plants are concerned, in which the demands for low-pressure steam and current are fairly relative and under single control, but I am doubtful as to how the scheme would work out in practice if a central station were supplying current to one class of consumer and steam to another without any relation between the two demands. From the point of view of thermal efficiency the system is ideal, but unfortunately the ideal can be applied only in limited cases and does not lend itself to general application. Apart from the demands for current, the demands for steam are two-fold, industrial and domestic. Some industrial demands would be for 24 hours per day, and 7 days per week, whilst others would be for only 47 hours per week. The power plant would therefore have to include condensing equipment for dealing with the exhaust at hours when the factories were shut down. It is only under conditions such as obtain in chemical works that the current and steam demands are relative. The domestic demand for steam would be mostly for heating purposes, with a little topping-up by electric fires. That is all very well for the winter, but nobody wants houses steam-heated during the summer. There is, however, not very much difference between a winter day-load and a summer day-load, so that in this instance the condensing plant is again required. Given a works or group of works in which the demands for current and steam have about a 90 per cent annual load factor or even 90 per cent annual plant factor, the arrangement is worth while, but with an ordinary generating station having an annual electrical load factor of from 20 to 30 per cent and a steam load factor of considerably less than that, I think it will not prove a paying proposition. The cost of the necessary steam-supply mains and equipping houses and works for

changing over to this system would be enormous, and it is doubtful if many people would be induced to change. The electrical industry has already had an uphill fight against vested interests; is it wise voluntarily to invite other difficulties? The Manchester experiment is quoted as an example, but that is a case in which only a small proportion of the steam is being supplied. If the Manchester Corporation were going to sell at low pressure the whole of the steam that they require to raise in order to meet the electrical power demand, they would approach the question of power houses, power plants, and the scheme in general from a totally different angle.

Mr. C. Crompton (*communicated*): There is no doubt that hotels possessing a central heating plant, and factories which use low-pressure steam for industrial purposes, can, and do, generate electricity on quite a small scale as a by-product, at a price which makes it extremely difficult to supply them with power at a profit. If such economies are possible on a small scale, one would have expected the use of exhaust steam for heating to have developed to a greater extent than it has done, at any rate in this country. I think one reason is probably that in the early days designers of power stations had not before them the advantages to be obtained by this saving of heat, and it was not realized to what distances steam or hot water can be conveyed economically for heating purposes. I think also that the combination of power and heating plants has not always been wisely carried out. I believe, however, that it is now generally recognized that given favourable conditions great economies are possible. For instance, a brewery lends itself to this treatment. I recently got out some figures in connection with the electrification of a country brewery, and the advantage shown in the use of exhaust steam for heating was very considerable. The chief difficulty in using exhaust steam on a large scale now appears to be one of wayleaves, and hence we have the opinion expressed that the authors' proposals are not practicable, because, owing to the great congestion of pipes, sewers and cables already in the London streets, room for subways for hot pipes could not be found. London does not cover the whole field, however, and even if in a congested town the question of wayleaves is insurmountable, which I do not believe to be the case, there must be a number of large factories, or groups of factories in the country, where no question of wayleaves comes in, and where the advantages of a central power plant supplying exhaust steam would be enormous, especially if any of the factories required exhaust steam for industrial purposes. During the past 3 or 4 years I have carried out the design and installation of such a combined heating and power plant for factory purposes. This plant, which had a boiler capacity of 100 000 lb. of steam per hour, and an electrical capacity of 3 000 kW, was arranged to deliver exhaust steam for heating either from "bleeder" turbines or direct from the boilers through reducing valves at 10 lb. gauge pressure. All "process" steam was taken direct from the boilers through reducing valves at 100 lb. gauge pressure, and all steam to the factory was conveyed in a subway, the transmission being up to distances of nearly a mile. Not only was there a big saving in steam, but the saving in capital cost, owing to the reduced boiler capacity required, and saving in buildings, was considerable, and one set of coal- and ash-handling plant and overhead bunkers served both systems. Again, the men handling coal and ashes would have been wanted for the heating plant in any case, and the only extra men to increase the cost of generation of electricity were the engine-room and switchboard men. Another great cause of saving was the fact that the load factor on the boiler side was ideal, and boiler stand-by losses were therefore reduced to a minimum. The figures obtained on test indicated that, when running on full load under favourable conditions, the consumption of steam for electric power, treating the supply of electricity as a by-product and allowing for a steam consumption for heating based on economical practice, worked out as low as 5·5 lb. per kWh, and the cost of electricity on the same basis, summer and winter, allowing for the supply of electricity when heat was not required, worked out at a figure which would compare not unfavourably with that of a super-station. I do not agree with Mr. Barker's statement that workmen's cottages cannot be economically supplied with heat from a central supply. This is probably the most difficult class of property to heat from a central station at a financial profit, and in the case of an existing town of workmen's dwellings possessing their own heating apparatus, central heating may be difficult to justify. The cost of individual heating to the householder, however, is not wholly in the cost of coal, and central heating removes one very large source of expense, namely, the maintenance of a kitchen boiler. Where the buildings are not yet built, for instance in the case of one of the new garden cities, credit may also be taken for a very considerable saving in the cost of the buildings themselves, as they can be built without chimneys or fire-places. I recently had to investigate the figures for a combined electric power and heating scheme for a new garden city of 2 000 dwellings, and, taking the above considerations into account, it appeared that there was not much in the cost, one way or another, but the consumer benefited in convenience, as he had no grates to clean or fires to lay, etc. Had there been any industrial demand for steam or electricity to even up the load, the centralized scheme would have benefited largely. Though I am far from saying that the use of exhaust steam is by any means always practicable, I am inclined to think that there is more scope for a saving in this direction than is usually realized. Turning now to the technical conditions under which the use of exhaust steam for heating makes a saving, I have heard it stated more than once that a combined power and heating scheme is only worth while if there is a good balance between the supply of steam and electricity. Where back-pressure engines are used it is at least very important that all the steam used by the engines should be absorbed by the heating plant, and that electricity is not generated under very uneconomical conditions and the steam wasted. In a small private plant, such as an hotel or brewery, the balance between

electricity and heat is to a certain extent under control, but in a central station dealing with a public supply this is not the case, and condensing sets bleeding to the heating mains are in my opinion essential. Even so, good balance is of considerable importance, and this can usually be adjusted by choosing a suitable exhaust pressure. The actual consumption of steam in the engine is not so important; for instance, in the factory plant I have mentioned, the full-load steam consumption was about 82 000 lb. per hour, and, if the turbine consumption had been doubled at the same exhaust pressure, the total increase in consumption would have been only about 3 per cent, while by raising the exhaust pressure from 10 lb. to 20 lb. at the guaranteed turbine consumptions for these pressures the total consumption would have risen only 2 per cent. If, however, Mr. Haden's figures of 60 lb. exhaust pressure and 115 lb. engine consumption are taken, the increase in total consumption would have been 14 per cent, involving an annual extra cost of between £4 000 and £5 000, and this would have been mostly due to the fact that at this consumption the heating plant would not absorb all the steam from the turbines, and the system would be out of balance. The question of balance, therefore, is really important and the exhaust pressure requires to be very carefully chosen in each case to suit the local conditions. Difficulties in regulation may be due to the use of back-pressure engines, and with engines of this type they may be considerable. What happens is that the heating plant requires less steam, the pressure rises in the exhaust main, and the engine loses power. The governor then opens to maintain the electric load, the set works under less economical conditions and takes more steam, and the pressure in the exhaust rises still further, and so on. With bleeder sets this difficulty should not arise, and difficulties are, I think, mostly due to a want of careful study of the problem. The turbine governor must deal with variations not only in the electrical load, but in the quantity of steam demanded by the heating plant, and with variations in the steam conditions inside the turbine owing to fluctuations of steam pressure in the heating main. Turbine builders have a tendency to treat the heating main as a convenient means of regulating the turbine, and the heating main has to take the amount of steam which it is convenient to give it, in view of the load on the turbine. This should not be allowed. So long as the heating main can take it, all the exhaust should be used for heating, no steam should pass to the condenser, and all turbine regulation should be dealt with without interfering with the "pass in" valve. This valve should, however, be over-controlled by the governor against running away. In a factory all the electrical load is shut off very rapidly at the commencement of the mid-day interval. The pressure in the heating main may be fairly high, and its capacity may be large, and the pass-in valve open. Under these circumstances even if the main stop-valve is completely closed by the governor, there may be enough steam in the heating main to drive the low-pressure end of the turbine and raise the speed to a dangerous extent. Under these circumstances the pass-in valve should be closed by the governor. This has been arranged at the factory mentioned above, and I believe the regulation is quite satisfactory.

Mr. A. E. A. Edwards (*communicated*): Our industries depend on our coal, the reserves of which are very low compared with those of other countries, and to make matters worse we export 30 per cent of our coal. Each ton of coal exported would produce £50 worth of goods if used in this country. If exported

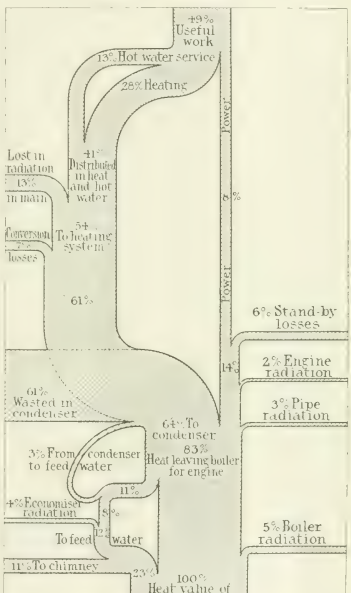

FIG. A.—Diagram showing heat losses in steam engines and how they may be recovered.

we get, say, £2 for it. We ought to be taking the most careful steps towards the preservation of our coal reserves. Yet in this particular matter under discussion, the utilization of the 92 per cent of heat wasted in steam plants, we lag far behind America and Germany, in which countries serious attempts are being made to deal with the matter. Mr. Haden said that 10 million tons of coal are used in electric supply stations, 50 per cent of this going to the condenser and being available for heating purposes. The domestic requirements of the country are 40 million tons, most of which is used in the towns. The heat requirements

of towns for domestic consumption alone are therefore 8 times the heat available from the power stations. Fig. A illustrates in graphic form the B.Th.U. losses between the boiler and the power available, and shows what a large amount of heat there is in the exhaust steam ready for use, but now wasted. There is sufficient load in hot water supply to private houses—exclusive of heating—to absorb more than twice the heat available from all the power stations. The figures Mr. Barker gave are purely hypothetical. Neither he nor any cottager would care to live in such a comfortless atmosphere, under such conditions as he outlined. The large power stations are admittedly often fixed in unsuitable positions, and that is one of the mistakes that should be remedied before still larger stations are fixed in even more unsuitable places where there is "plenty of water." Within 5 miles of Hammersmith there are 27 supply stations. Let us examine any centrally heated institution, at which hot water is metered, and we shall find that not a single one will give an efficiency [=(heat put into the water)/(B.Th.U.'s in the coal burnt)] as low as 15 per cent for hot water alone without taking note of what is used for heating, cooking, laundry, and sterilizing purposes, or for radiation losses. Yet this paltry 15 per cent is the ultimate goal which we were promised on paper, though it was known that the results obtained in the Newcastle-on-Tyne district are due to the long-hour running and the large amount of waste heat and power which could not be reproduced anywhere else in the whole country. The ideal electric supply is from small stations situated about as far apart as the present electric substations. They should distribute heat, power and light, and they would then give an efficiency of not less than 20 per cent. Many of them would give 40 per cent. It may be said that the cost of wages would be increased out of proportion, but this is not so; some of the smaller stations of only 1 000 kW capacity spend less per unit in wages than does a city like Birmingham with a capacity of 66 000 kW. I think I have proved that it is not necessary to surround the stations with industries as Mr. Whysall suggests, but that the domestic load will absorb all the power available. Mr. Whysall mentions running mains through basements, and talks about obtaining wayleaves. If we attempted to run heating mains on private property, or if it were decided to run high-tension electric mains from super-stations, it would add greatly to the cost. It is sufficiently difficult now to get permission to run a telephone wire across someone else's property, and the Government's scale of payment of compensation would ruin everything. Let us examine a concrete case: A workhouse on 19 acres of ground, inmates 53 to the acre, cost of heating plant £5 000, and cost of coal £5 000 a year. Is it better to use this coal at an efficiency of 30 per cent or over or to be content with the 8 per cent or even the 15 per cent possible if the exhaust steam were not used? In this case we have an area not more closely populated than a housing scheme area. The capital outlay is not excessive, and the economy is £1 000 a year. Economy has been attained by combined heating and power schemes, and is being attained every day. The difficulties of utilizing the exhaust will not be overcome at the first attempt.

Mr. A. H. Foyster (*communicated*): There is no doubt that a demand has now arisen for central heat-supply stations. The small boiler used for heating a block of offices or a single building has an economy in coal consumption compared with an open grate fire in each room, but is very uneconomical when compared with large boilers grouped together in a central station. While coal was cheap this waste was not a serious matter to the consumer, but the increased price of coal has made the question of its economy a very vital one. Granted the greater economy of a central heat supply, the question which affects us is whether a further saving cannot be made by combining the production of steam for heating purposes and for generating electricity. A little while ago I was associated in the design and installation of a station for the supply of heat and electricity. The loads were unbalanced and each had to be met as demanded. In this station steam is generated at 190 lb. pressure and 220 degrees F. superheat. The steam can be passed direct to the heating main from the boilers through valves which reduce the pressure to 10 lb., or it can be used to run the turbo-generators condensing, or it can be passed through these sets to the heating main, the turbines running with 10 lb. back pressure. In winter when the heating demand is greater than the electrical, the heating main receives part of its steam from the turbines and the remainder is automatically made up by steam passed through the reducing valves from the boilers. It happened that, for a short time in winter, steam could not be passed out from the turbines; in other words the two systems were run independently except that there was a combined steam-producing plant. Although the consumption of steam by the turbines was reduced to about a third, the total coal consumption rose considerably, for the same demand for heat and electricity, above the figure it had been under the combined system. This gave a practical illustration of the economy in coal consumption to be gained by the use of a combined station. This will perhaps be taken as showing that from the heat-supply point of view it pays to generate electricity as a by-product. The gain from the electrical supply point of view is in the reduction of capital cost charges for not only does the extra plant required—boilers, heating main, and exhaust pumps—have a high load factor, but all the existing boiler plant has its load factor considerably raised. The question of the most suitable back pressure to use in each case is one that requires the most careful consideration. In proportion as the back pressure is raised the steam consumption of the turbine per unit generated is increased, and therefore where the generation of electricity is a by-product, the income from this source is decreased; on the other hand, the sectional area of the heating main, for the delivery of a given quantity of steam, decreases, and with it decreases the cost of the main and also the space it occupies in the ground. The authors of the papers differ in their suggestions between 2 lb. and 60 lb. back pressure for mains up to a mile in length. My own experience has been that for mains

of this length the back pressure should usually be between 10 lb. and 20 lb. While $\frac{1}{2}$ lb. pressure is sufficient at the consumer's premises for heating the air in the buildings, this steam requires to be dry, the point aimed at of course being to utilize as much of the latent heat of steam as possible, and this is best effected by a reduction of pressure on entering the premises. When there is a demand for heat for cooking purposes the pressure of the supply must be high enough to allow 8 to 10 lb. pressure at the ovens. As the district to be supplied becomes more extended a higher pressure will have to be used, but, as additional mains will have to be laid to deal with the increased demand, it should not be a great complication in working to supply at two pressures and thus allow the steam supplied to the nearer consumers to earn as much as possible from the generation of electricity. Naturally the proximity of the heat-supply station to the demand is all-important and the difficulties of finding a suitable site with railway-siding facilities is very great in crowded towns. I think, therefore, that Mr. Haden's suggestion to utilize the discarded power stations is a valuable one. Many of these are centrally situated and the acquisition of suitable buildings, with siding and ccaling facilities, standing at the reduced capital cost they would fetch as substations, would allow capital to be spent on altering the turbines, to make them suitable for working on back pressure, and on making the boiler plant thoroughly efficient, for economy in steam production is as vital to the heat-supply system as it is to the electrical. Further, there is a staff available who are trained in steam production and electrical generation, with a knowledge of the district to be served which should be invaluable in enabling them to determine where the heat demand is likely to be and how the mains can best be run to supply it.

Mr. R. Nelson (*communicated*): The two papers are complementary; the first seeks to show how under favourable local conditions the heat which is normally rejected from a generating station may be increased so as to make it available for use, the electricity supply authorities in this case being sellers of surplus heat, whereas the second advocates co-operation between manufacturers who use process-steam and neighbouring electricity works, the supply authorities in this case being purchasers of surplus heat. Mr. Haden suggests that the heat value of coal used in the production of electricity would be more completely utilized by combining the production of power with that of heat. This means in effect combining the sale of electricity with the sale of heat. The proposal involves an increased consumption of coal per unit of electricity generated, but it is claimed that the extra coal for power generation would be more than off-set by the saving of coal used for heating purposes, the heat being distributed in the form of hot water in pipes. The proposal just outlined was examined very generally towards the end of the war in an effort to suggest some further means of economizing coal, and two conclusions seemed to be indicated: (*a*) That a combined heat-power scheme for a compact area or township is feasible and if applied generally within the area or township would be economical as regards coal consumption to the extent of about 50 per cent of the coal now used for heating; (*b*) that so long as generating stations in populous districts continue to be run the saving in coal to be effected over the whole country would be of the order of 2 or 3 million tons per annum, but that this annual saving would be reached only gradually and by the expenditure of a great deal of energy and effort in the way of propaganda. It is further conditioned by the provision of some practicable method of preventing the heat from being wasted by prodigality on the part of the individual consumer. These conclusions assumed that a corresponding saving in fuel would be effected as a result of more efficient methods of applying heat for heating purposes. It is, however, by no means certain that this would happen, for heat users, having been accustomed to a certain annual expenditure on fuel, would be less likely to attempt to reduce this expenditure than to take advantage of obtaining twice or three times as much heat for the same money in order to obtain greater comfort. If this happened and the population, having more heat at their disposal, were enabled to live under better conditions as regards warmth and particularly ventilation—not having to be so careful to conserve the heat they could open their windows—the nation would probably benefit even more by the improvement in public health than by the saving in fuel. It would be interesting if Mr. Haden could give the coal saving effected and, if possible, the financial results, in a concrete case such as that which he mentions in Manchester. When all has been said that can be said in favour of the proposals which Mr. Haden outlines, however, I feel that I shall not be alone in failing to follow what he advocates in connection with capital stations. These are designed exclusively from the point of view of the economical generation of current and can hardly in the nature of things be favourably located for the sale of heat. To allow the possible sale of heat to interfere in any way would form a monumental instance of the reversal of cause and effect. In saying that "in new large stations" it is hoped to reach 8 per cent thermal efficiency, Mr. Haden must surely have meant to say 28 per cent. The stations of which he speaks no doubt served well their time and generation but they belong to the last century. But the case that Mr. Haden puts forward does not require any reference to capital stations; it applies only to old and comparatively small stations placed in populous districts where such stations continue to be run.

Mr. Whysall's paper might be studied with profit by whose who use, as many manufacturers do, large amounts of process steam and whose works are within the area of an electricity supply undertaking. Mr. Whysall advocates that the benefits to be derived from co-operation should be equally divided between the parties, and I support that contention. When a scheme for the utilization of surplus heat is actually in being, the electricity supply authority sometimes finds that lack of correct methods of measurement, plus the effect of intermittent working, have induced the owner of surplus heat to over-estimate, quite genuinely, the amount of surplus heat he has available,

and possibly at the same time to under-estimate, again quite genuinely, his own power requirements. Mr. Whysall's dictum as regards an equal share of resulting profits should therefore be placed in the fore-front of a co-operative agreement, and provision should be very carefully made in the body of the agreement to secure that under all the varying conditions likely to arise in practice this first principle is not undermined. Community of interest is necessary in order to secure the best results from co-operative agreements such as Mr. Whysall contemplates.

Mr. A. C. Pain (*communicated*): This subject is of the utmost importance, as we cannot continue to throw away with the cooling water 60 per cent of the heat in the coal. A system which involves such a waste stands self-condemned and in a few years will be considered to be as obsolete as the Newcomen engine was after Watt brought out the separate condenser. Sooner or later a more efficient system must be evolved by the co-operation of electrical and heating engineers. What is wanted is goodwill and fair play on both sides. A municipal engineer recently told the manager of a company using a large quantity of steam in their manufactures, and therefore in a position to generate current at low cost, that if he agreed to the company's power plant being run in parallel with the corporation electric supply, nothing would be paid for any current fed into the mains, but the company must pay, and at a high price, for any current received from the mains. This is a very narrow view for a corporation engineer to take. The corporation electric supply is a public utility and should be run in the interests of the public and not as a monopolistic trust. It should be like a bank, prepared to receive as well as pay out, or like an insurance company, designed to safeguard the industries in the district and foster their development. Public electric supply companies or corporations should be required by law to accept supplies of current at a certain percentage (say about 50 per cent) of the price charged for current furnished in the same district, under the same conditions. If this were so, the problem of the utilization of waste steam, waste gases, or waste heat of all kinds would largely solve itself, because people or firms having the command of such waste heat would become alive to the fact that they had a valuable asset and proceed to develop it. For the rest, it is not to be expected that a full and complete scheme for the solution of the problem of distribution of heat in a town or model village will be evolved otherwise than gradually. As usual, it will have to be evolved step by step, based on the experience of what has been already accomplished. No doubt, heating engineers can instance cases of heat being distributed over large areas with inconsiderable loss, and in many cases the system is in successful operation on a large scale in hotels, institutions or residental blocks of flats. For example, the Savoy Hotel, where 70 000 gallons of water at a temperature of 160° F. to 170° F. are used per day, the water being heated by the exhaust steam from the electric generating plant. Or again, the Queen Anne's Mansions, a large block of residential flats comprising about 500 sets of rooms. There are two systems in this block of flats. The steam-heating system, which includes a radiators, hot-plates, etc., is supplied from the exhau of 5 or 6 pumps, which are almost continuously workin This system is exhausted at about 5 to 10 inches vacuu by means of pumps. Included in the steam-heatir system are the drying chambers, calenders and oth appliances in the laundry. There is also the hot-wat system, this being supplied from surface condense into which the electric light engines exhaust. In fac the whole of the hot water for the building is supplie by the cooling water from the surface condense The water required for heating, etc., is pumped throu the condensers, and the amount is regulated accordi to the discharge temperature required, usually abo 160° F., the vacuum varying between 2 and 15 inche As the water passes away from the condensers it pumped up to the top of the building for the necessa hot-water service, a continuous circulation bei provided to maintain the desired temperature. Th system makes for the best possible efficiency, as t degree of vacuum is the highest consistent with t temperature of water required. If the system c be successfully applied to such a huge aggregate dwelling houses as represented by Queen Anne Mansions, is it such a big step to proceed further ar apply the same system to a whole street, or a whc town in sections, each with its own power and heatir station running in parallel with the public electr supply, or, if sufficiently near, supplied with he as well as electric current from the public electr supply station? In addition to the low therm efficiency, any new supply station must suffer fro the enormous increase in the capital cost, which M E. Cross in his paper on "Present-day Commerci Problems in Electricity Supply" states will be 4 times the pre-war basis. This is a strong argume in favour of any system which will utilize existir supply stations. Indeed, it has been pointed o that on this account almost any existing supply statio should be able to supply current at lower cost tha a new station. If this applies to a station operati condensing, it would apply to a much greater exte if the station were run as a waste-heat station. Anoth aspect of the case is that whereas the cost of productic in electricity supply stations was formerly on t down grade, now it is steadily mounting up and charg are being increased. Those in charge appear to unable to restrain this tendency, and the effect, whil very bad for the trade of the country, will give a stimul to private and independent power plants, as the wor will find that they can generate for themselves mo cheaply than the super-power stations can suppl This is another reason for the supply stations settir their houses in order and welcoming the co-operatic of those who are in a position to generate curre cheaply by the utilization of steam or waste gases waste products of any kind.

Mr. C. I. Haden (*in reply, communicated*): In the di cussion as a whole there is little which calls for reply, as general there is an absence of question or criticism, but strong feeling that, as the principles have been amp proved in so many cases, something should be attempte

I appreciate the remarks made by Colonel Crompton as coming from one who has had so large an experience in the development of electricity. The convenience of electric heating for small rooms and local radiation is freely admitted. The increasing use thereof does not, however, lessen the waste of heat at the generating station, which is the main point under consideration, and it is satisfactory to know that Colonel Crompton approves of the retention of existing electric generating stations as heating stations, where suitable.

Mr. Selvey credited me with using the expression "pure energy," but I did not refer to it. In criticizing Mr. Barker's remarks he referred to the probable large consumption of hot water if an unlimited supply were available. Daily records showing an average consumption of 50 gallons per house have been taken in one large installation, and, assuming each house has 5 inhabitants, the average is 10 gallons per head. Mr. Selvey further mentioned an expected thermal efficiency of 20 per cent. I admit this is a great improvement, but I fear it will be a long time before the majority of the stations in this country reach that figure.

Mr. Nobbs dealt particularly with American practice and the charging rates, and viewed with apprehension Mr. Whysall's figure of 10d. per 1 000 lb. with coal at 10s. per ton. If 1d. increase per 1 000 lb. were charged for every rise of 1s. per ton, it will be seen that with fuel at 50s. per ton the charge would be 4s. 2d., and I understand that Mr. Whysall intended the charge to be 10d. per 1 000 lb. for every 10s. in cost of coal per ton, which amounts to the same, viz. 4s. 2d.; my figure was 4s.

Mr. Crompton alluded to the exhaust pressure which I mentioned, viz. up to 60 lb. per sq. in. I gave this as a probable maximum that would be necessary for certain industrial purposes or to save the cost in mains for distribution, and I quite agree that in separate installations the pressure should be adjusted to balance the loads as nearly as possible.

Mr. Nelson asked whether I could give any figures of the coal saving in Manchester. The total heat supplied to the various buildings would require a consumption of about 3 000 tons per annum if used in separate installations. The whole of this is not saved as I understand that, under present conditions, about 25 per cent of the total heat is supplied by live steam. I have no figures showing the financial results. Mr. Nelson thought I meant 28 per cent thermal efficiency when I said 8 per cent, but I was not so optimistic. Mr. Selvey mentioned a figure of 25 per cent which it was hoped to attain. When this has been accomplished I will offer my hearty congratulations. I stated that 1 120 B.Th.U.'s in 1 lb. of coal were converted into electrical energy, and this is 8 per cent of the 14 000 B.Th.U.'s assumed. The average weight of fuel per unit quoted in a recent return by the Electricity Commissioners was 3·32 lb., which gives 3 718 B.Th.U.'s, or more than actually exist in the kilowatt-hour. The average figure must therefore be less than 1 120 B.Th.U.'s per lb.

Mr. F. H. Whysall (*in reply, communicated*): Colonel Crompton's remarks with regard to electric heating are very much to the point, but the authors had no intention of making a comparison with electric heating. As Mr. Biggin says, "A good many of the points made by Colonel Crompton with reference to the advantages of heating by electrical appliances might just as truly have been applied to heating by steam or hot water. The point under discussion, however, is the utilization of exhaust steam from generating stations."

Mr. Patchell gives some very interesting information with regard to Detroit. He also mentions a case where an industrial user of steam found it more expensive to take the supply of electricity from the public authority than to generate it himself with a pressure-reducing plant, which bears out the contention that it is sometimes more economical to combine the use of steam for industrial purposes with the generation of electrical energy.

Mr. Barker refers to the heating of cottages and contends that the cost of supplying exhaust steam for heating purposes would be prohibitive. This would certainly be the case under the circumstances detailed.

Mr. Selvey's description of two kinds of energy, which he terms "high grade" and "low grade," helps the conception of the problem materially, and he is correct in his statement that "we undoubtedly require very large quantities of what may be termed low-grade energy." Mr. Selvey refers to the heat-balance diagram showing 10 per cent efficiency, and is of the opinion that we have in sight a station which will improve this figure to 25 per cent and may reach an efficiency of 30 per cent. Unfortunately, 10 per cent is nearer the truth in most power stations, and a perusal of the Reports of the Board of Trade Coal Mines Department on "Central Stations Thermal Efficiencies" will bear this out. In several cases where higher efficiencies have been obtained it has been found that they have been realized at the expense of other stations running in parallel, or in cases where the heat contribution of a waste-heat supply was largely a matter of estimate.

Mr. Nobbs refers to American practice in district heating, and discounts it as being a survival of wrong methods. His criticism of the figure of 10d. per 1 000 lb. as the proper price for steam with coal at 10s. per ton is understood to mean that he considers the figure to be too low. Compared with the cost of heating by means of a hot water system with a coal-burning boiler, calculations show that at this price steam is 25 per cent dearer. His scale of American charges is a valuable contribution to the discussion for purposes of comparison, and the figures for a month's working of a district heating station showing 49·6 per cent overall efficiency are very interesting.

Mr. Driver contends that if a firm would put down plant in the right way and utilize exhaust steam, they would supply electricity at a price which no municipality or super-power station could approach. My experience is that this is not borne out in practice unless the plant can be run at 100 per cent load factor. A supply authority has a tremendous advantage in capital charges and diversity factor.

Mr. Haden supports the case for the co-operation between electric supply departments and industrial undertakings, and mentions the economy that might be obtained by supplying steam from a central

station where heat is required as well as light and power.

Mr. Allen admits that although he approached the problem of power generation and utilization of exhaust steam in a large group of works with considerable prejudice, he was in a very short time convinced that it was economically sound and whatever little difficulties existed in supply and operation could and would be overcome. It is agreed that the relation between the electric load and the steam load materially affects the problem, and the authors have stated that each case should be considered on its merits.

Mr. Crompton thinks that one reason why the use of exhaust steam for heating has not been developed is that in the early days designers of power stations had not before them the advantages to be obtained by this saving of heat and it was not realized to what distances steam or hot water could be conveyed economically for heating purposes.

Mr. Edwards appears to advocate as ideal, an electric supply from small stations situated about as far apart as the present electric substations, and the abolition of super-power stations. This is going much further than the authors thought of suggesting.

Mr. Foyster emphasizes the importance of suitable back pressures in each case and the effect of the proximity of the heat supply to the demand. He is in favour of Mr. Haden's suggestion that discarded power stations should be utilized as heating stations.

Mr. Nelson emphasizes the benefits to be derived from co-operation between manufacturers who use large amounts of process steam and an electric supply undertaking when the two are in the same area. He also makes some justifiable strictures with regard to the points to be embodied in the agreement between parties.

Mr. Pain thinks that the solution of the problem will be evolved gradually and that a municipal supply is a public utility and should be run in the interests of the public and not as a monopolistic trust; also that it should be, in common with a bank, prepared to receive as well as pay out. These views are very modern.

In conclusion, it must be said that the discussion proves that the problem is too important to be neglected, and if it results in engineers being prompted to consider the possibilities of each case as it comes before them, the discussion will have valuable results.

THE INTERCONNECTION OF ALTERNATING-CURRENT POWER STATIONS.

By L. Romero and J. B. Palmer, Associate Members.

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Summary.

This paper discusses the special factors to be considered in designing an interconnecting link between two alternating-current power stations, with particular reference to power factor and power factor control.

Equations are given in the Appendix for determining the power factor of the line current with any given load and voltage boost, and the voltage boost required to transmit any given load at a given power factor.

The three possible conditions of voltage relationship between the power stations, and their effect on the power factor of transmission, are stated.

Various types of booster for controlling the power factor are discussed.

The effect of power factor variation is pointed out, and the desirability of fully considering and deciding on the power factor of transmission before installing a line is emphasized.

Tables are given to illustrate the effect of transmission power-factor on the cost of transmission and on station power-factors.

The synchronizing power of the line is briefly discussed and its value is worked out in the Appendix.

Introduction.

Since November 1916, when Mr. J. S. Peck read a paper * on this subject, several interlinking schemes have been put into commission or projected, and further experience in the operation of interconnected power stations under everyday working conditions has become available.

The authors have had occasion to study the principles underlying the operation of interconnected power systems, more especially from the point of view of the rating and selection of apparatus required to control the voltage and power factor in transmission lines connecting power stations of the same frequency; and also with a view to investigating the variation in power factor which accompanies the transmission of power through interconnectors.

It is, of course, generally recognized that the paralleling of two systems is not merely a question of running a cable from one station to the other and closing a switch; but the authors feel that while in some quarters the difficulties accompanying parallel operation have been exaggerated, in others the necessity for a careful preliminary survey of the possibilities has not been fully appreciated.

The purpose of this paper, therefore, is mainly to show the importance of power-factor phenomena in interconnectors, both on technical and on economic grounds.

* *Journal I.E.E.*, 1917, vol. 55, p. 61.

While the conclusions arrived at on the latter grounds apply with equal force to transmission lines which are not interconnectors, it is intended only to deal with the general problem of transmission lines connecting power stations.

In making a preliminary lay-out of an interconnector scheme the designer will be confronted at the outset with the problem:—What variation in power factor will result from interconnection with a given voltage "boost" applied to the interconnector? And conversely:—What voltage "boost" will be required to transmit power at a given power factor of transmission? As far as the authors are aware, equations for the solution of these problems are not at present available in a form so simple as to permit of rapid calculation. They have therefore added an Appendix giving formulæ for estimating these values.

General Operating Conditions.

It is necessary to emphasize one of the first principles (although it may appear to be a statement of the obvious) since there seems to have been some confusion of thought in the past concerning the transfer of power from one station to another.

The division of load in any desired proportion between two alternating-current power stations depends wholly on the adjustment of the steam supply to the prime movers. The mere adjustment of the field strength of generators, or the raising by other means of the voltage at the "sending" end of the interconnector, only causes wattless kilovolt-amperes to flow around the circuit formed by the generators at the two power stations and interconnecting cable, the true power or kilowatts remaining unaltered, except for the load added by the copper loss in the interconnector. Adjustment of voltage, in addition to steam control, is necessary in certain conditions, which will be described.

When current flows through a circuit having resistance and reactance (such as an interconnecting cable, with or without step-up and step-down transformers) the voltage at the two ends of the circuit will differ either in magnitude or phase displacement, or both. Fig. 1 is a modification of the well-known Kapp diagram for the pressure regulation of a circuit containing resistance and reactance. The angles ϕ_1 and ϕ_2 represent respectively the phase displacement of the voltages at the receiving and sending stations with respect to the current in the line. The impedance of the line, and its accompanying voltage-drop, represented in the figure by IZ, causes the phase displacement between the two voltages.

For a given load the position of the voltage triangle with respect to the current vector will vary with the value of $(E_2 - E_1)$, which is the difference in magnitude of the station voltages. Since the cosines of the angles ϕ_2 and ϕ_1 are the power factors of the load in the line at the sending and receiving ends respectively, it will be apparent that the power factor of transmission at one end of the line can be controlled and kept constant by varying the voltage of one station with respect to the other, as the load varies.

There are three main conditions of voltage relationship

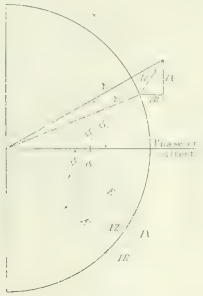


FIG. 1.

E_1 = Voltage at receiving end of interconnector.
E_2 = Voltage at sending end of interconnector.
IZ = Impedance drop in line and transformers.
IR = Resistance drop in line and transformers.
IX = Reactance drop in line and transformers.
$\cos\phi_1$ = Power factor in line at receiving end.
$\cos\phi_2$ = Power factor in line at sending end.

under which power can be transmitted between two power stations, viz.

(1) *Station voltages constant and equal.* The mean power factor of transmission will remain at a constant leading value, the power factors at the station ends of the interconnector varying (but only within small limits) in opposite directions as the load varies or reverses in direction.

(2) *Station voltages constant and unequal.* The power factor of transmission will vary with the load in the direction of lag to lead as the load increases, and vice versa as the load decreases. This method is suitable only for transmission of power in one direction.

(3) *Station voltages varied by booster or other means as the load varies.* The power factor may be kept constant at any desired value within the range of the voltage variation available.

Under condition (1) power up to the capacity of the line may be transmitted in either direction without varying the voltage or mean power factor at all. This condition is shown in the dotted portion of Fig. 1, where the two voltage vectors E_1 and E_2 are of equal length. Both these vectors lag behind the current vector of reference, i.e. the load in the interconnector is at a leading power factor throughout its length, the mean angle of lead depending on the ratio of reactance to resistance in the circuit. For a given line the power factor of transmission at the two ends of the line will vary in opposite directions with the load, the mean power factor remaining constant.

This method might be used for a line connecting two stations each with a load at or near unity power factor, and where it was necessary to reverse at short notice the direction of transfer of power in the line. Under these conditions

$$\tan \alpha = \frac{R}{X}$$

where α is the mean angle of lead of the current,
X is the reactance of the line, and
R is the resistance of the line.

By making X as large as would be safe from the point of view of synchronizing power, the mean power factor of transmission in some cases might be fairly near unity, and power could be transmitted under these conditions in either direction without any very serious interference with power-factor values elsewhere. Unfortunately, however, the majority of power stations are probably unable to receive and absorb into their systems a bulk supply at a leading (or even unity) power factor, without very serious disturbance to their operating conditions. This method has, therefore, only a limited field of application unless special measures are taken to supply the large wattless component which might be required. This feature will be referred to later in the paper.

Under condition (2) the voltages are usually fixed to give the most desirable power factor of transmission at full load. This method is actually used with success in a number of cases where load is transmitted in one direction only. Its advantage over method (1) is that it makes it possible to transmit a fixed load at any desired constant power factor, but it also has some disadvantages. It is only suitable for transmitting power in one direction, as a reversal of power would flow at a low leading power factor. Further, as the load varies the power factor of transmission also varies within wide limits, and lastly, with a large voltage-difference in the circuit it would hardly be practicable to operate without a regulator of some kind for the purpose of reducing the voltage-difference when switching into or out of parallel, as without this provision the sudden making or breaking of the large wattless current which would flow at no load would have serious effects on the busbar pressure at one or both stations. These considerations appear to rule out a fixed voltage-difference, where that difference has to be large, although this method gives fairly good results under favourable conditions, and where the transmission of power is to be in one direction only.

In one installation which the authors have in mind, the load on the interconnector is fairly steady, and the normal power factor of the interlinked systems

is high. The main transformers are fitted with tappings giving the ordinary commercial range of adjustment on the lower-voltage side, and the results have been generally satisfactory.

Condition (3) will, in the opinion of the authors, be necessary in the majority of cases. The variation of voltage may be obtained either

(*a*) By varying the busbar voltages at one or both stations, or
(*b*) By introducing "boost" in the interconnecting line.

In the case of power undertakings distributing alternating current, variation of busbar pressure for this purpose is inadmissible, since it means a corresponding variation in voltage at consumers' terminals. This method of power-factor control can therefore be eliminated except for installations where the power to be transmitted is small and the interconnecting cable short. In almost all cases, whether regulation is effected by automatic voltage regulator or by hand, a fixed pressure is aimed at, and restored after longer or shorter periods of variation, and it will therefore be assumed throughout the paper that the busbar pressures at the interconnected power stations are kept constant.

The introduction of boost into the interconnector is therefore the only generally applicable method of varying the voltage relationship between the two stations. The variable boost in the line can be introduced by—

Induction regulators,
Static boosting transformers with step-by-step regulators, or
Variable regulating tappings on the main transformers.

Types of Regulator.

Both the step-by-step and induction types of regulator have been used for many years for feeder regulation, and more recently for power-station interconnector regulation. Both types have certain advantages and disadvantages, some of which have become more apparent under the latter conditions.

For large powers and high voltages, the step-by-step regulator is at a disadvantage owing to the difficulty in building remote-control switchgear which will connect the tappings of the main or auxiliary transformers in the proper sequence without breaking the main circuit. The latter requirement involves the provision of pilot contacts connected to preventive resistances or reactances in order to avoid short-circuiting sections of the transformer winding when passing from one tapping to another. The preventive resistances should be capable of carrying approximately full-load current at a voltage equal to the difference in pressure of adjacent tappings, and in frequent operation the duty may be very heavy. The difficulties encountered in the past with this type of apparatus are not insurmountable, and apparatus which it is believed will give satisfactory operation is now in process of development.

Contactor-type and face-plate type step-by-step regulators are limited to pressures of about 3 000 volts, and their use generally entails the provision of step-down transformers to bring the voltage on the switchgear within this limit, with an additional transformer to apply the boost at the required voltage. These transformers would each require to have a capacity in the same proportion to the full-load rating of the interconnector as the voltage boost is to the line voltage (allowing for transformer ratio), and the otherwise simple and inexpensive arrangement of contactors or face plates becomes formidable under these conditions. Frequent inspection and overhaul is necessary, and this, in many cases, could be given only at considerable inconvenience.

Contactor-type regulators have been constructed, which vary the voltage on the line by shifting the neutral point of a star-connected three-phase transformer progressively up or down the winding, 4 or 5 taps being provided for this purpose. In order to limit the voltage between the contactor and earth to safe limits, the neutral point must be earthed in the regulator, and the system can, of course, only be arranged in connection with a star-connected winding. In spite of these limitations, however, this type of regulator undoubtedly has its field of application.

An induction regulator is in effect a transformer having one winding movable with respect to the other. It can be wound for pressures up to 11 000 volts and at this voltage is equivalent to the two auxiliary transformers and switchgear constituting the step-by-step regulator. There are no contacts to be kept in adjustment, while in fineness of voltage variation it is equal to a step-by-step regulator with an infinitely large number of contacts.

In America a combination of the step-by-step and induction-type regulator has been developed successfully for the control of electric furnaces, and has been applied to some extent to the regulation of feeders. In this type a boosting transformer is provided with a few tappings spaced along the winding in comparatively large steps, the induction regulator being connected to the tappings successively by a system of transfer switches giving a fine variation of voltage. As, in this arrangement, the induction regulator is only required to have a kilovolt-ampere capacity equal to $(1/n) \times$ (total kilovolt-ampere capacity of the equipment), where n is the number of tappings, the method appears to be a promising one.

In the three-phase induction regulator the secondary induced pressure is constant in magnitude, the variation in the resultant (regulated) voltage being obtained by the alteration in the phase angle between the applied and induced voltages. Since the phase displacement of the resultant voltage with respect to the current in the line is fixed by the difference (in magnitude) between the resultant voltage and the voltage at the receiver station, the phase of the applied voltage with respect to the receiver voltage is altered when the resultant boost is less than the maximum, but the power factor of the sending-station load carried by the interconnector is not altered, since the phase of the line current is shifted by a similar amount, neglecting losses (see Fig. 2).

Where only two power stations are connected together,

there is not much objection to this; indeed, the introduction of the phase angle caused by the induction regulator may be beneficial in certain particular cases. Where, however, there are more than two stations interlinked, the phase angle introduced by the induction regulator may give rise to complications. For this reason it is desirable to wind the induction regulator with its series winding in two halves connected in reverse series. By this means the resultant voltage is in phase with the applied voltage (see Fig. 3). It should not be overlooked in laying out interlinking schemes

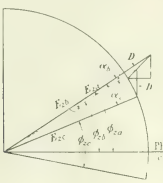


FIG. 2.

$\cos \phi_{2R}$ = Power factor in line at sending end, at full load and full boost.
$\cos \phi_{2}$ = Power factor in line at sending end, at half load and half boost.
$\cos \phi_{2c}$ = Resultant power factor of interconnector load on sending station.
D = Voltage added by induction regulator (constant).

where interconnection at one point only is in contemplation at the moment, that the development of the scheme may require further interconnections at a later period, and in the authors' opinion it is generally desirable to install double-wound induction regulators.

Interlinking schemes are often required to be reversible, that is, it must be possible to transmit power in either direction at short notice. This requirement simplifies the lay-out and design of the main and auxiliary

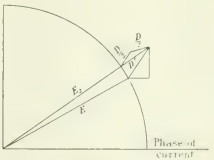


FIG. 3.

apparatus to the extent that the plant at one end of the line can be a duplicate of, and interchangeable with, that at the other end; but on the other hand the cost of the installation may be increased by it. In the case of a scheme where it is required to deliver 10 000 kVA to either station from the other, and regulator capacity of 10 per cent of the total power is required to compensate for the line and transformer drop; the main transformers, line, and regulators at both ends of the line would have to be capable of dealing with something over 11 000 kVA, although the apparatus at the receiver station would actually carry only 10 000 kVA.

Provision for a reversible transfer of power also prevents the adoption of the method of boosting shown diagrammatically in Fig. 4. This method, when permissible, gives a considerable economy in material. If the transmission of power were to be in one direction only, it would be possible to combine methods (2) and (3) previously given and, by winding the main transformers so that their voltage ratios differed by a predetermined amount, regulators of half the capacity could be used by merely reversing the direction of boost. The following example will make this clear

In Fig. 4, station A is to transmit power to station B. Both stations run at 6 600 volts, the transmission voltage being 33 000 (nominal). The line and transformer constants are such that a total boost of 12 per cent, or approximately 800 volts, is required. This boost is made up of 400 volts at each end of the line, using one regulator at each end of the line and boosting on the lower-voltage side. By winding the main transformers for a ratio of 6 400/33 000 volts (nominal) at the sending station, and 33 000/6 800 volts (nominal) at the receiver station, a reversible booster capable of giving 200 volts

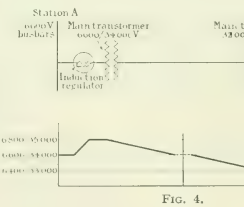


FIG. 4.

(i.e. 3 per cent, or half the capacity) would be sufficient for the purpose.

In interconnection schemes involving the transmission of large amounts of power over considerable distances, it is often desirable to install regulating plant at both ends of the line, each regulator providing half the total capacity required; otherwise the voltage boost provided by the regulator might, in some cases, bring the resultant voltage to a value too far above the nominal transmission voltage. Fig. 5 shows the distribution of voltage which would be obtained if the typical installation shown in Fig. 4 were equipped with a regulator at the sending end only. The figure is based on the open-circuit ratio of the transformers, as it is assumed for comparative purposes that the impedance of the circuit is concentrated in the line.

If in this example the transfer of power were required to be reversible, the distribution of voltage would be as shown in the dotted portion of Fig. 5. The 12 per cent booster would not be large enough for this condition since, if station B were the sending station, the current, and therefore voltage-drop, in the line, would be approximately 14 per cent greater than if the induction regulator were at the sending end, for equivalent kilovolt-amperes transmitted.

The chain-dotted line in Fig. 5 shows the voltage

distribution for this example, with 10 000 kVA received at A, and with the same boosting capacity as when station A was the sender station.

As far as the authors are aware, no regulating apparatus of the step-by-step type or of the induction type has

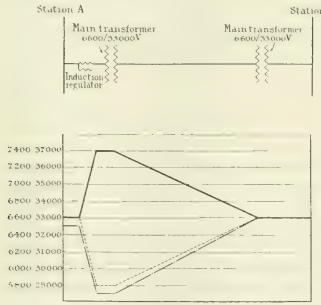


FIG. 5.

yet been developed for pressures exceeding 11 000 volts. In these circumstances it is necessary for the regulators to be connected so that they operate by varying the voltage applied to the low-tension windings of the main transformers, and, while there is no objection

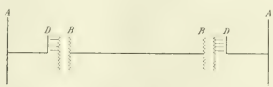


FIG. 6.

AA; Generating station busbars.
BB; Main transformers with tappings on low-tension side.
DD; Regulating switchgear.

to this on general grounds, transformers which have to give their full output over a range of primary voltage naturally are larger and more expensive than those which work at a fixed voltage.

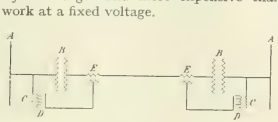


FIG. 7.

AA; Generating station busbars.
BB; Main transformers.
CC; Auxiliary transformers (step-down).
DD; Regulating switchgear.
EE; Auxiliary transformers (series).

Figs. 6 and 7 show alternative arrangements of auxiliary apparatus. In Fig. 7 the series windings of the step-up transformers are placed on the higher voltage side of the main transformers, and in this arrangement the latter are not subjected to the variable applied voltage mentioned in the preceding paragraph.

When a series boosting transformer is used as in Fig. 7 it is essential that the circuit through the primary windings of the series transformer should be closed under all conditions. Remote electrically-operated step-by-step regulators should be arranged so that failure of the auxiliary power supply does not cause this winding to be open-circuited. Otherwise, the main current in the series winding, being unopposed, would all be available to magnetize the core, and the resultant voltage induced in the open-circuited winding might cause serious damage to the insulation and even destroy the transformer.

Effect of Power Factor Variation.

The power factor at which the transmission of power over the interconnector is to be effected is an important consideration, since obviously the capacities of the line, main transformers, and auxiliary apparatus, depend on it. Further (and especially when the power factor of the normal connected loads on the interlinked power stations is different), in certain cases it might easily happen that the station receiving power would find itself loaded with wattless kilovolt-amperes to such an extent as to neutralize the advantage anticipated from the interconnection. When the two stations concerned are under the control of one authority, the division of the wattless component will probably be decided on the basis of joint maximum economy, but when one authority is purchasing power in bulk from another, the power factor at which the sale of power is to be effected should be agreed upon after full investigation.

Table 1 shows the effect on the station power factor for a hypothetical installation consisting of two power stations A and B, an interconnecting cable, and step-up and step-down transformers. Station A has a normal load of 20 000 kVA at 0·9 power factor (lagging); and station B has 25 000 kVA at 0·7 power factor (lagging). Station B is to purchase power up to 10 000 kW from A.

The station power factors and transmission efficiencies have been calculated for four different values of power factor of transmission at the receiver end of the line, viz.

(1) At 0·7 lagging, the normal power factor of the receiver station (col. 1).
(2) At 0·92 lagging, equivalent to 0·9 lagging at the sending station (the normal power factor of the load on that station) (col. 2).
(3) At unity power factor (cols. 3 and 3*a*).
(4) At 0·83 leading, this being the power factor at which transmission could be effected, for this particular case, with no voltage difference in the line (col. 4).

Columns 1, 2, 3 and 4 are calculated on the basis of one regulator, at the sending end only. Column 3*a* is inserted for comparison with column 3, to show the slight variation caused by placing a regulator of half the total capacity at each end of the line.

Transmission at the power factor of the normal load of the receiving station naturally has no effect on the plant power factor at that station; the sender station power factor, however, suffers by the addition supplying an ordinary large consumer whose apparatus operated at a power factor lower than the normal.

Transmission at the normal power factor of the sending station's normal load would leave that power

TABLE 1.

Station B receiving 10 000 *kW at Various Power Factors.*

		Power Factor at Receiving End of Interconnector as Determined by Voltage Difference									
		0·7 (lagging)		0·92 (lagging)		Unity		Unity		0·83 (leading)	
		kVA	P.F.*	kVA	P.F.*	kVA	P.F.*	kVA	P.F.*	kVA	P.F.*
Station A	Own load	20 000	0·9 lag	20 000	0·9 lag	20 000	0·9 lag	20 000	0·9 lag	20 000	0·9 lag
	Transmitted to B	16 300	0·68 lag	11 780	0·9 lag	10 560	0·996 lag	10 600	0·996 lag	12 070	0·89 lead
	Total load on A	35 670	0·81 lag	31 780	0·9 lag	30 090	0·95 lag	30 130	0·95 lag	29 270	0·98 lag
Station B	Own load	25 000	0·7 lag	25 000	0·7 lag	25 000	0·7 lag	25 000	0·7 lag	25 000	0·7 lag
	Received from A	14 280	0·7 lag	10 800	0·92 lag	10 000	Unity	10 000	Unity	12 070	0·83 lead
	Resultant load on B	10 720	0·7 lag	15 660	0·48 lag	19 360	0·39 lag	19 360	0·39 lag	25 740	0·29 lag
Transmission loss as per cent of kW delivered		10·6 %		6·1 %		5·2 %		5·5 %		7·6 %	
Booster capacity ..		2030 kVA (14·2%)		970 kVA (9%)		560 kVA (5·6%)		574 kVA (5·74%)		Nil	
Col. No.		1		2		3		3 (*a*)		4	

* P.F. = Power factor.

TABLE 2.

Comparison of Annual Cost of Transmission of 10 000 *kW at* 0·7 *and Unity Power Factor, corresponding to Cols.* 1 *and* 3 *of Table* 1.

One 0·2 *sq. in.* 3*-core cable,* 33 000 *volts,* 16 *miles long.*

	Power Factor in Line at Receiving End			
	0·7 Lagging		Unity	
	£	%	£	%
Annual Capital Charges.				
Cable, at 8½ %	8 500	33·5	8 500	33·5
Transformers, at 11 %	2 816	11·5	2 002	7·9
Regulators, at 11 %	869	3·4	286	1·1
Synchronous condensers, at 11 %	Nil	Nil	1 650	6·5
Annual Value of Energy Lost.				
I^2R losses assuming 40 % load factor, and losses equal to 28 % of losses at 100 % load factor, at 0·9d. per unit	9 888	39	5 362	21·1
Iron losses, at 0·5d. per unit	3 285	13	2 737	10·8
Total losses in synchronous condensers	Nil	Nil	3 679	14·5
Total Annual Cost of Transmission	25 358	100	24 216	95·4

of the load represented by the bulk supply at a power factor lower than its normal power factor. In most cases this would be considered an equitable arrangement, and station A would be no worse off than if it were

factor unaffected, but the position would probably not commend itself to the engineer at station B, as his station power factor would drop considerably. Transmission at the leading power factor corresponding to

equal voltages has even less to recommend it; in the hypothetical case tabulated the kilovolt-ampere load on the generators at station B is actually larger than it would be if no supply were being taken from station A. The only advantage of this method is that all auxiliary boosting apparatus is eliminated.

Transmission at unity power factor has some considerable advantages. The capacity of the line and transformers, as shown in the table, can be materially reduced, while the transmission losses are a minimum. The power factor at station B is, however, objectionably low and, if this system is to be adopted, steps would have to be taken to deal with the excessive wattless component which station B would have to provide. Fortunately, the means are to hand in the synchronous condenser, but it must not be assumed that the provision of a machine of this type is always the best solution of the low-power-factor problem. The synchronous condenser merely supplies the wattless component which would otherwise be borne by the generators, at one or both stations, and the capital cost of a synchronous condenser equipment would not be justified except in those cases (which may be numerous) where it would be impossible to carry the wattless component on the generators.

In the case analysed in Table 1, the power factor of the load on the receiving station is only 0·7, and it is probable that this station could not suffer a diminution of its power factor as a result of the bulk supply being received at a higher power factor. The receiving station would then be faced with two alternatives: either to take the bulk supply at 0·7 power factor, or at a higher power factor and install synchronous condenser plant.

The first alternative would, for the case illustrated in Table 1, merely transfer the wattless component to the sending station, the generator power factor of which would be reduced from 0·9 to 0·81. If these generators were designed for operation at 0·9 power factor, it might not be possible to run them at a power factor much lower than this, and in these circumstances a synchronous condenser equipment would be a necessity.

If synchronous condensers were installed, the most economical power factor of transmission would be unity. Table 2 shows the comparative annual cost of transmission for the line illustrated by Table 1 at two power factors, viz. 0·7 (lagging) and unity, the latter necessitating synchronous condensers. A small saving is shown by their use, but the authors do not suggest that this saving alone would be sufficient to justify them, and they should only be installed in circumstances where a substantial saving on the total cost of transmission could be effected by them. Perhaps the strongest case for their use would be when an existing transmission line is fully loaded at a low power factor, and it is required to transmit additional power; an installation of synchronous condenser equipment would then compare favourably as regards cost with the only alternative, i.e. another cable with its accompanying boosters, transformers and switchgear. Objection may perhaps be taken to the values assumed in Table 2 for the units lost. These values may, however, be varied over a fairly wide range without greatly affecting the comparative results obtained.

In the authors' opinion, while no general case can be made out for the use of synchronous condensers in connection with the interlinking of power stations, particular cases will arise in which substantial economies can be effected by their use, and this possibility should always be kept in mind when installing or extending an interconnecting transmission line.

Synchronizing Power.

The authors have met with cases of interconnected alternating-current power stations where the synchronizing power of the interconnecting line was not sufficient to produce satisfactory parallel running under the conditions of load fluctuation met with in practice, and while they do not think that trouble is likely to be experienced from this cause in the 33 000-volt and higher voltage interconnection schemes which will be laid down in this country in the near future, they feel that this paper would be incomplete without some reference to the matter. The synchronizing power which will flow between two stations, for a variation of θ from the stable phase angle β between the two busbar voltages, is shown in Appendix II to be equal to

$$3E_1E_2\frac{X}{Z^2}[\sin(\beta + \theta) - \sin\beta]$$

The differences between the value given above and those given in Mr. Peck's paper and in a paper by Mr. E. C. Stone * respectively, are apparently due chiefly to the different definitions of synchronizing power adopted.

If the angle β is calculated for the full load of the line, the synchronizing power at full load for any variation from angle β can be obtained from the above formula. It is interesting to note that for any given resistance of line the synchronizing power is a maximum when

Reactance of line = Resistance of line.

This is important because, while the resistance of the line is generally fixed by economic considerations, the reactance of the line can usually be designed for the best results at a very small extra cost, or none at all. The authors are of opinion that the reactance should never be less than the resistance, and for parallel running at fixed pressures the higher the reactance (within limits) the better the power-factor regulation. In interconnectors at pressures above 6 600 volts, the reactance of the step-up and step-down transformers will usually bring the total reactance of the circuit to a figure well above that of the resistance.

The calculation of the synchronizing power of the line is, of course, only half the problem, and it would next be necessary to decide whether this line synchronizing-power would be sufficient to hold the two power stations in satisfactory synchronism. The strongest desynchronizing forces normally operating during the parallel running of turbo-alternator stations will be

* *Transactions of the American Institute of Electrical Engineers*, 1910, vol. 38, p. 1651.

sudden large variations of the electrical load on one station or the other.

When there is a steady load on the two stations the power sent through the line will depend on the power supplied to the prime movers and the load on the busbars of each station, and the difference of phase angle between the station voltages will be exactly that angle required to transmit this load through the interconnector.

If an additional load is suddenly thrown on to station 2, say, no additional load can flow from station 1 until an alteration in the phase angle between the two station voltages has taken place. This statement assumes that no reduction in the voltage of station 2 takes place when the load is thrown on.

At the instant when the additional load is applied, the phase angle begins to alter rapidly owing to the slowing down of station 2, and this alteration of phase angle will inevitably swing beyond the correct angle for the new load, and be swung back by the synchronizing power. An oscillation of power is thus set up through the line which, under this state of affairs, may be likened to an elastic mechanical coupling.

The initial deceleration of the plant in station 2 at the instant when the sudden additional load is thrown on will vary inversely as the moment of inertia of the rotating parts of the plant, which moment, other things being equal, will vary as the capacity of the plant. This means that in a small station the synchronizing power will have to arrest the comparatively high-velocity swing of a mass having a small moment of inertia, and in a large station the comparatively low-velocity swing of a mass having a large moment of inertia.

From the above considerations the authors, without having investigated the problem very deeply, venture the opinion that the magnitude of these oscillations and therefore the adequacy of the line from the point of view of satisfactory synchronous running, depends only on (*a*) the strength of the original desynchronizing force, and (*b*) the synchronizing power of the line.

The capacity of the stations would not therefore directly affect the magnitude of the oscillation although, as the instantaneous variations of power will generally be larger on a large system than on a small one, the capacity of the plant might be said to have an indirect effect on the magnitude of the oscillations of power through the line.

It is not proposed in this paper to deal with the amount of synchronizing power necessary for satisfactory parallel running under any given set of conditions, but the authors are of the opinion that the adequacy of the synchronizing power of a proposed interconnecting line should, if possible, be calculated theoretically before the line is installed, as the results of installing a line with inadequate synchronizing power might be very costly indeed.

APPENDIX I.

In making a preliminary estimate of the costs and capacity of an interconnector installation, it is necessary to ascertain the booster capacity required for a given load in kilowatts delivered at a fixed voltage at the receiver station. As mentioned in the paper, it is highly desirable that the power factor of transmission should be decided early in the negotiations, and in any case it is often desirable to make a series of estimates based on different power factors, so that either a known or assumed value of power factor is available for calculation purposes.

The following formulæ for determining the amount of booster capacity necessary are sufficiently accurate for practical purposes. Three-phase transmission only is dealt with, and the effect of electrostatic capacity in the cables is ignored, this being permissible in the great majority of cases likely to be met with. In the form given, the formulæ are suitable for estimating the boost required in installations containing step-up and step-down transformers, and where the two stations generate at the same voltage; but they are readily applicable to other conditions.

List of Symbols.

E_1 = Voltage between line and neutral at the receiver end of the extra-high-pressure cable, i.e. normal busbar voltage multiplied by the no-load ratio of the transformers.

E_2 = Voltage between line and neutral at the sending end of the E.H.P. cable at full load.

R = Total resistance of the E.H.P. line and transformers, in ohms per conductor.

X = Total reactance of the E.H.P. line and transformers, in ohms per conductor.

(*Note.*—It is convenient to assume that the resistance and reactance of the transformers is concentrated in the E.H.P. winding.)

Z = Total equivalent impedance per conductor of the E.H.P. line and transformers $= \sqrt{(R^2 + X^2)}$.

I = Current per conductor, in E.H.P. line at full load $= \dfrac{\text{kW}_1 \times 1\,000}{3E_1 \times \cos\phi_1}$.

$\cos\phi_1$ = Power factor in line at receiver end at full load.

$\cos\phi_2$ = Power factor in line at sending end at full load.

kW_1 = Power in kilowatts to be delivered at the receiver station.

kVA_2 = Power in kilovolt-amperes at the sending station end of the line.

The voltage to be added by the booster, in terms of the E.H.P., is

$$E_2 = \sqrt{(E_1\cos\phi_1 + IR)^2 + (E_1\sin\phi_1 - IX)^2} \quad \text{(when } \cos\phi_1 \text{ is lagging)} \quad . \quad . \quad (1)$$

and $\sqrt{(E_1\cos\phi_1 + IR)^2 + (E_1\sin\phi_1 - IX)^2}$ (when $\cos\phi_1$ is leading) . . (2)

The booster capacity in kilovolt-amperes for full load $= 3I(E_2 - E_1)$ . . . . . (3)

The power factor at the sending end $= \cos\phi_2$, where

$$\phi_2 = \arctan \frac{E_1\sin\phi_1 + IX}{E_1\cos\phi_1 - IR} \text{ (for lagging power factor)} \quad (4)$$

and $$\arctan \frac{E_1\sin\phi_1 - IX}{E_1\cos\phi_1 + IR} \text{ (for leading power factor)} \quad (5)$$

When the booster capacity is to be divided, and boosters of half the total capacity placed at either end of the line, the value of the current (I) in the E.H.P. line will no longer be equal to $(\text{kW}_1 \times 1\,000)/(3E_1 \cos \phi_1)$, since the voltage at the receiver end of the E.H.P. line will be less than E_1 by the amount to be boosted. It is possible to calculate I for this condition accurately, but it is generally more convenient provisionally to fix E_2 by Formula (1) or (2), and correct with a value for I derived from the expression

$$\frac{\text{kW}_1 \times 1\,000}{3[E_1 - \frac{1}{2}(E_2 - E_1)] \cos \phi_1}$$

Estimation of the Power Factor at the Sending End of the Line, with a Given Constant Voltage Difference in the Line, for a Given Load in Kilovolt-amperes at the Sending End.

In Fig. 8 the power factor of transmission (sending end) $= \cos \phi_2$

$$\text{or} \quad \left.\begin{aligned} \phi_2 &= \alpha - \epsilon_2, \text{ when } \phi_2 \text{ is lagging} \\ \phi_2 &= \epsilon_2 - \alpha, \text{ when } \phi_2 \text{ is leading} \end{aligned}\right\} \quad . \quad . \quad (6)$$

$$\alpha = \text{arc tan} \frac{IX}{IR}$$

$$\epsilon_2 = \text{arc cos} \frac{E_2^2 + IZ^2 - E_1^2}{2E_2 \times IZ}$$

In general, the power factor at the sending end is lagging if $(E_2 - E_1)$ (i.e. the voltage difference provided by the booster or other means) is greater than the ohmic

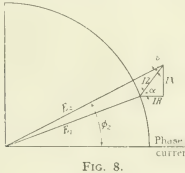


Fig. 8.

drop, and is leading if $(E_2 - E_1)$ is less than the ohmic drop.

Formula (6) covers cases where the power factor of transmission is known or can be assumed, that is to say, where the value of I is approximately correct. Where it is required to estimate the power factor of transmission with a given voltage difference for a given load in kilowatts, and where a value for the power factor cannot be assumed, a closely approximate solution is given by the following :—

$$\tan \lambda = \frac{(E_2 - E_1) - IR}{IR} \times \frac{R}{X} \quad . \quad . \quad . \quad (7)$$

where

$$I = \frac{\text{kW} \times 1\,000}{3 \times \frac{1}{2}(E_2 + E_1)}$$

and λ = mean angle of lag or lead.

Conversely, the voltage boost or difference necessary to transmit a given load in kilowatts at a given mean power factor of transmission ($\cos \lambda$) may be obtained approximately from the formula

$$E_2 - E_1 = \frac{X}{R}(\tan \lambda) IR + IR \quad . \quad . \quad . \quad (8)$$

APPENDIX II.

Synchronizing Power of the Interconnector.

It is desired to find an expression for the synchronizing power which will flow through the line for any variation of the phase angle between the two station voltages, from the correct phase angle for the load being transmitted. In Fig. 9, using the same symbols as before, with the following additions :—

P_S = Power in watts delivered to sending end of interconnector.
P_R = Power in watts delivered to receiving end of interconnector.
β = Phase angle between E_2 and E_1.

$$P_R = 3E_1 I \cos \phi_1 \quad . \quad . \quad . \quad . \quad . \quad (9)$$

$$= \frac{3E_1}{Z} \times IZ \cos \phi_1 \quad . \quad . \quad . \quad (10)$$

$$IZ = \frac{E_2 \sin \beta}{\sin \epsilon_2}$$

Substituting this value for IZ in (10) we obtain

$$P_R = \frac{3E_1}{Z} \times \frac{E_2 \sin \beta}{\sin \epsilon_2} \cos \phi_1 \quad . \quad . \quad . \quad (11)$$

Now, $\phi_1 = \alpha - (180 - \epsilon_2)$ and $\cos \alpha - (180 - \epsilon_2)] = \sin \alpha \sin \epsilon_2 - \cos \alpha \cos \epsilon_2$ (12)

Substituting this value of $\cos \phi_1$ in (11) we obtain

$$P_R = \frac{3E_1E_2}{Z} \times \frac{\sin \beta}{\sin \epsilon_2}(\sin \alpha \sin \epsilon_2 - \cos \alpha \cos \epsilon_2)$$

$$\frac{3E_1E_2}{Z} \times \sin \beta (\sin \alpha - \cos \alpha \operatorname{cotan} \epsilon_2) \quad . \quad (13)$$

Again, $\operatorname{cotan} \epsilon_2 = \frac{E_1 - E_2 \cos \beta}{E_2 \sin \beta}$

$$\sin \alpha = \frac{X}{Z}$$

and $$\cos \alpha = \frac{R}{Z}$$

Substituting these values in (13) we obtain

$$P_R = \frac{3E_2E_1}{Z}\left[\sin \beta \frac{X}{Z} - \frac{R}{Z}\left(\frac{E_1 - E_2 \cos \beta}{E_2}\right)\right]$$

$$= \frac{3E_2E_1}{Z^2}\left(X \sin \beta + R \cos \beta - R \frac{E_1}{E_2}\right) \quad . \quad (14)$$

In a similar manner it may be shown that

$$P_S = \frac{3E_2E_1}{Z^2}\left(X \sin \beta - R \cos \beta + R \frac{E_2}{E_1}\right) \quad . \quad (15)$$

If the phase angle β be increased to $(\beta + \theta)$

$$P_R = \frac{3E_2E_1}{Z^2}\left[X \sin(\beta+\theta) + R\cos(\beta+\theta) - R\frac{E_1}{E_2}\right] \quad . \quad (16)$$

and $$P_S = \frac{3E_2E_1}{Z^2}\left[X \sin(\beta+\theta) - R\cos(\beta+\theta) - R\frac{E_2}{E_1}\right] \quad (17)$$

By subtracting (14) from (16) and (15) from (17) we see that the increases of P_R and P_S are respectively as follows :—

Increase of $P_R = \frac{3E_2E_1}{Z^2} \times$

$$[X \sin(\beta+\theta) - X \sin\beta + R\cos\beta + R\cos(\beta+\theta)] \quad (18)$$

and increase of $P_S = \frac{3E_2E_1}{Z^2} \times$

$$[X \sin(\beta+\theta) - X \sin\beta - R\cos\beta - R\cos(\beta+\theta)] \quad (19)$$

The increase of P_S less the increase of P_R is equal to the increase of the line losses

$$= \frac{6RE_2E_1}{Z^2}[\cos\beta - \cos(\beta+\theta)]$$

Therefore the increase of power flowing through the line, after deducting the increase of line losses,

$$= \frac{3XE_2E_1}{Z^2}[\sin(\beta+\theta) - \sin\beta] \quad . \quad . \quad (20)$$

This is the general expression for the value of synchronizing power of the line, where β is the phase angle

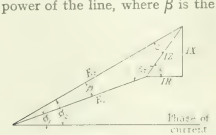


FIG. 9.

between the station voltages necessary to transmit the load as fixed by the power admitted to the prime movers, and the load on the busbars of the two stations ; and θ is the instantaneous deviation from β.

For a three-phase circuit the synchronizing power in kilowatts is therefore

$$\frac{X}{Z^2} \times \frac{3E_2E_1}{1\,000}[\sin(\beta+\theta) - \sin\beta] \quad . \quad . \quad (13)$$

where E_1 and E_2 are the voltages from phase to neutral, and X and Z the reactance and impedance of the interconnector, in ohms per conductor.

APPENDIX III.

Since the paper was compiled one of the authors has had the opportunity of studying the long-distance high-voltage transmission systems in the United States and Canada, and it has been suggested that some observations on the operation of interconnected stations in America might add to the usefulness of the paper.

It is difficult to compare British and American practice in the interconnection of power systems, because the conditions of generation and distribution are often so entirely different in the two countries. The case the authors had in mind in writing the paper was that with which they have had to deal most often, namely, where two or more independent undertakings, each with its own generating station situated inside its own comparatively dense area of supply, contemplate a junction for the purposes of mutual assistance and support. In these circumstances the distance between the load centres is generally short, requiring only moderate voltages on the interconnectors, and the close proximity of the power station to the load forbids any considerable variation of busbar voltage.

In the United States the electricity supply industry is largely in the hands of power companies operating over what we should consider very large areas. In those parts of the United States where water power is not available and where power supply is given from steam power stations, the conditions as regards interlinking are not entirely dissimilar to those prevailing in Great Britain, although there are probably very few instances where large undertakings of high "load density" are so close together as they are in Great Britain. In the case of companies using water power there is generally very little resemblance between their system of distribution and that of the undertakings in England. For instance, the Pacific Gas and Electric Company, operating in the North-Central portion of the State of California, have an area of supply of 47 000 square miles (in 1916), i.e. only 3 823 square miles less than the area of the whole of England with its total of nearly 300 undertakings.

It is evident that these conditions are very much more flexible from the point of view of interconnection than those which obtain in denser areas. In the hydro-electric companies' areas there are often a number of power stations, themselves a considerable distance apart, forming a group from which power is conveyed to the load centres perhaps 100 miles from the nearest power station in the group. These power stations, having little or no load connected to the lines between them and their nearest neighbours, are not hampered to any extent by the necessity for very close regulation of busbar pressure. The division of load between the power stations is determined by the amount of water available at the different sites, and it is one of the most important duties of the load dispatcher to utilize the water to the best advantage. It may happen in the case of a company having power stations scattered over a wide area that a shortage of water at one plant occurs at a time when there is a surplus elsewhere, and the station with the surplus would adjust its voltage so as to maintain approximately unity power factor on the generators, and therefore develop the maximum possible kilowatt output so that the surplus water could be used to the best advantage. The station with the shortage of water would raise its voltage so as to take as much of the wattless component as possible from the other station, running its generators perhaps up to the full-load kilovolt-ampere rating but at a

lower power factor, with correspondingly small demand on the water.

The regulation of power factor by variation of busbar voltage was ruled out of consideration in the paper, and in the circumstances usually met with in England the authors see no reason for altering this view. Also Table 1 shows that power systems with their own load to consider would be seriously incommoded if they had to carry any considerable extra wattless component, but in the cases described, where the power stations are under one control, and the load dispatcher's authority is absolute, voltage and power factor can be varied deliberately over a fairly wide range, in the interest of maximum economy, and regulating devices on the lines interconnecting the power stations, as described in the paper, are rarely necessary.

It must not be inferred from this, however, that the supply is inferior to that given in this country in respect of voltage variation at consumers' terminals. Many of the power companies operating long transmission lines have synchronous condenser plant at the main receiver substations and, in some cases, steam-driven generating stations in the cities. Generally the voltage charts taken at points in the low-voltage distribution system show remarkably little variation in voltage. In one oil-fuel station the generators were fully loaded at about 0·4 power factor (lagging), it being necessary in this particular case to relieve the long-distance lines of some of their wattless component in order to maintain the voltage in the city.

Power companies supplying large areas from a number of generating stations in parallel interconnect their system with neighbouring concerns for mutual interchange of power in the same way as some of the smaller self-contained undertakings in Great Britain have done. Such interconnections do not present any particular problems to undertakings accustomed to the operation of their own group or groups of power plants; to the receiver the interconnection merely represents another power station feeding into the system, to the supplier another consumer. Neither party appears to pay much attention to the question of the power factor at which power is delivered; in the long-distance systems, when the receiver makes the interconnection in order to maintain his voltage at a certain point, he is willing to deal with the wattless component entailed by the voltage he asks for. The spirit of co-operation, even between competitive concerns, is a marked characteristic of the American power companies.

A feature of the distribution of electricity in the United States which has a very marked effect on the operation of interconnected power stations and systems, and indeed on every phase of generation and operation, is the remarkably high load factor. An investigation of the technical and financial aspects of an interconnection which might show unpromising results to one accustomed to think in terms of the load factors usually obtained in England, might have a very different aspect when considered in the light of an overall annual load factor as high as 65 per cent. The effect of high load factor is seen in the steadiness of the loads on interconnectors, and the absence of necessity for any considerable voltage variation. The annual load factors of the principal power companies in California and also some of the interconnected power systems in England are given below, the figures being for the year 1920. The American figures are from the *Electrical World* and the British from the *Electrical Times*.

	Maximum Load	Load Factor
	kW	Per cent
Pacific Gas and Electric Co. ..	259 000	65
Southern California Edison Co.	213 450	57·1
Great Western Power Co.	80 600	57·8
San Joaquin Light and Power Corporation	47 180	72·4
Los Angeles Bureau of Power and Light	46 500	41·0
Southern Sierras Power Co. ..	32 600	61
California Oregon Power Co. ..	20 335	80
Battersea (London)	5 160	31·36
Fulham (London)	4 800	32·25
Stepney (London)	10 240	31·49
Shoreditch (London)	4 881	21·35
Manchester	82 150	25·28
Salford	12 320	29·16
Wolverhampton	10 600	36·73
Midland Electric Co.	16 506	23·27

In California the power companies are interconnected from the Oregon State line in the North to San Diego in the South, a distance of 600 miles. The interconnections have been amply justified by results; the rainfall in California is very diversified, and before the interconnections were effected it was not uncommon for a shortage of water in one watershed to impose restrictions on the supply of electricity in the area supplied by the plant affected. Recently one company would have had to shut down owing to shortage of water if it had not been able to obtain assistance, up to practically full capacity, from its neighbours. The interconnections in California are generally of moderate capacity, and the normal interchange of power is small compared with the capacity of the interconnected systems. Some of the interconnections as originally installed have proved to be deficient in synchronizing power, and the supply by one company at non-standard frequency has necessitated interconnection through frequency changers. Some interesting features of the operation of frequency changers in the interconnection of power systems are described in an article by Mr. J. P. Jollyman of the Pacific Gas and Electric Co.*

Mr. Jollyman points out that a frequency changer introduces a phase angle which in the case of a machine converting from 25 to 60 periods per second might amount to 85 electrical degrees at full load, and is in effect equivalent to a long line of small capacity with an inherently low synchronizing power. For successful operation of frequency changers it is essential, if the size of the machine is to be in reasonable proportion to the amount of power actually interchanged, that the load fluctuations should be small.

* *Electrical World*, 1918, vol. 71, p. 1020.

As far as the author is aware, none of the interconnections in California has up to the present required any regulating apparatus in the sense described in the paper, but a certain amount of control is possible where the interconnection is made through a frequency changer, and, in those cases where transformers are interposed, the adjustment of tappings brings about a state of things somewhat similar to that described in the paper on page 297.

In the Eastern United States where the stations are mainly steam driven the conditions of distribution more nearly resemble British practice, although even here, with the exception of some of the very large cities, there is probably not that close proximity of dense load areas to which we are accustomed in England. One interconnector installation which the author had the opportunity of inspecting is of interest, containing as it does the largest induction regulators which have been constructed up to the present. The interconnector connects the Chester and Schuylkill stations of the Philadelphia Electric Company, and consists of two lines, each of approximately 20 000 kVA capacity. The distance between the stations is 14 miles, and the transmission pressure 66 000 volts. The two induction regulators are each rated at 1 750 kVA and are located at the Schuylkill station. The operation of these large induction regulators has been uniformly satisfactory, and their performance in regulating the voltage and power factor of the system has confirmed the correctness of the conclusions arrived at as to the characteristics and rating required. The authors desire to acknowledge their indebtedness to Mr. Raymond Bailey of the Philadelphia Electric Co. for some useful information on the performance of induction regulators and the operation of tie lines in parallel. The installation of the Philadelphia Electric Co. is fully described in a recent paper * by Mr. Bailey, which also contains an interesting investigation of the control of interconnectors in parallel loaded at a point along the line, which is a feature of this particular installation.

* *Journal of the American Institute of Electrical Engineers*, 1921, vol. 40, p. 462.

Discussion at The Institution, 2 February, 1922.

Mr. P. V. Hunter: The authors first of all emphasize the fact that in interconnection the exchange of energy is entirely controlled by the prime movers, and I think a recognition of this fact is the first essential to a proper understanding of any difficulties which may arise. I have seen cases of interconnection where there has been a tendency to what was called swinging of the phases, the suggestion being that there was some electrical instability. As a matter of fact, however, the condition was in no way due to electrical causes, but had an origin which was purely mechanical. It is true that the period of the oscillation was settled by electrical conditions, but the initiating force was mechanical, and is, in such cases, always of a mechanical, i.e. energy, nature. The next point which I should like to emphasize is the fact that, as shown in Fig. 1, when interconnection is carried out with constant and equal station voltages, unsatisfactory electrical conditions must inevitably result in ordinary commercial operation, because the station supplying the energy does not supply the wattless current. It is left to the station which receives the energy to supply this current, and in practice this method is inconvenient and uneconomical. For dealing with the various possible methods of regulation, the authors have discussed briefly and clearly three types of booster or regulator. It would have been of still greater value if they had been able to express a preference for one or other of these types with equal precision and finality. For myself, I have no hesitation in saying that I prefer the induction type of regulator, although I am quite aware that it is somewhat expensive and that in some cases it may be cheaper to install a switch or step-by-step type of regulator. On the whole, however, my opinion is that the induction type of regulator, particularly the type shown in Fig. 3, which is two-part, and where the resultant boosting voltage is in phase with the line pressure, justifies the extra expenditure. I should like to refer to the title of the paper, as I feel that industrially and economically the interconnection of alternating-current power stations is a matter of secondary importance. It is not, it seems to me, the power station that we wish to interconnect, but the networks. To provide a feeder at great expense for the sole purpose of carrying energy from one power station to another seems to me to be a proceeding which can be of only limited benefit, and of economic value in quite special cases only. The proper course, I think, must generally be to make the feeder which serves the purpose of interconnecting the power stations also supply the networks, i.e. any interconnector should also act as a network feeder. If this be done many of the difficulties of power station interconnection will disappear, and that these difficulties are really serious even a brief study of Tables 1 and 2 will make obvious. The difficulty of transferring load from one power station to another is very greatly lessened if the power station interconnector provided for this purpose also supplies a substantial load somewhere along its length between the two power stations. Fig. 4 shows an arrangement where the variable boosting pressure is supplied at each end of the interconnector, and I should like to point out that this arrangement not only has the advantage ascribed to it by the authors, but it also is of the greatest advantage in permitting load to be supplied from some point along the length of the interconnector. For this reason I am definitely of the opinion that the arrangement shown in Fig. 4 is the most satisfactory one to adopt for the majority of commercial applications.

Mr. F. H. Clough: The interconnection of two alternating-current power stations by means of a tie line is exactly similar to the interconnection of two alternators by means of a short length of busbar, except that in the first case the tie line usually has a considerable amount of impedance, and therefore when current is flowing through it there will be a voltage difference

between the two ends. If the two power stations must hold constant voltage, boosting apparatus must be installed to compensate for this drop in the tie line. The energy component of the current is controlled by the steam supply, and the inductive or magnetizing component by the excitation. It may be necessary to transmit either or both components over the tie line, depending upon the conditions in the two stations. The boosting apparatus need not be capable of fine gradation, as the engine governors and voltage regulators in the two stations will be able to take care of any variations that may occur when the amount of boost is changed. In order to keep the capacity of the boosting apparatus as small as possible the impedance of the line should be low; but consideration of the amount of energy that could flow into a short-circuit on the two systems may require the impedance to be of a comparatively high value. In calculating the amount of boost necessary I think the method of imaginary quantities as used by Steinmetz gives a simpler form of calculation than the use of trigonometrical quantities, and also allows the effect of the two components of the current to be more clearly seen.

Mr. H. Brazil: There is one point in connection with this subject that the authors have scarcely mentioned, i.e. the method of earthing the neutral points of the two interconnected systems. In Mr. Peck's paper to which the authors refer on page 287, the following methods of dealing with this point were suggested: (1) To earth only one station at a time and to make arrangements that when the stations were separated the other station should be earthed; (2) To earth one station only and to run an insulated cable from that station to the neutral-point busbar of the other station; (3) To place reactance or resistance in circuit with the neutral point at each station. In the discussion that followed, the first two of these suggestions were unfavourably commented on, and the third was considered to be the best. Since that paper was read the general consensus of opinion is in favour of inserting a resistance rather than a reactance in the neutral point and it is with that method of earthing that I propose to deal. The object of putting a resistance in circuit with the neutral is, first, to reduce the shock to the system when a fault occurs, and secondly, to limit the high-frequency current between the neutral points of the two stations which are to be connected. The fact that there is a difference of potential between the neutral points of the two alternators which are connected in parallel, the value to which this difference of potential can attain, and the current resulting therefrom are, I suggest, not very widely known. I propose to give some figures from actual practice. Now I am aware that in a new station where turbine sets only are installed and where these sets are probably duplicates of each other, the wave-form and turning moment will be exactly the same and there should therefore be no circulating currents. But we are now discussing the interconnection of two entirely distinct stations, and it is reasonable to suppose that in many cases the wave-form of the one will be widely different from that of the other, especially if the stations have been in existence some time. The maximum difference of potential I have observed is 1 200 volts, and the maximum current resulting therefrom when the neutral points were connected solidly to earth was 170 amperes. This current was passing from the neutral point of a 10 000-volt 3 000-kW generator of which the full-load current is about 170 amperes, so that the current in the neutral point was equal to the full-load current. This set would not run in parallel under these conditions, and an iron grid resistance was inserted in the neutral. In order to ensure that when a fault occurred sufficient current would pass to trip the circuit breakers, the resistance of the iron grid was made about 16·7 ohms. When running in parallel with reciprocating sets the current passing through the resistance was 64 amperes, the pressure across the resistance being about 1 080 volts. I then reduced the value of the resistance, and although the voltage dropped the current and also the kilowatt loss increased. If

Current in neutral	Pressure across resistance	Loss in external circuit	Resistance
amps.	volts	kW	ohms
64	1 080	69	16·7
86	1 030	88	12·0
106	970	103	9·0
144	880	127	6·1

these figures be plotted and the curve continued to the point of zero resistance the kilowatt loss would appear to be about 200. I wish to emphasize the point about the loss due to earth currents between neutrals because it is continuous and I am of the opinion that in the past too little notice has been taken of it. We have to aim at the reduction of these circulating currents to the lowest possible figures by increasing the value of the resistance, always bearing in mind that the latter must pass sufficient current to trip the circuit breakers when a fault occurs. The ideal resistance is one which, in addition to reducing the circulating current to a very small figure, will allow the full current to pass when a fault occurs. I suggest that the carbon-powder type goes a considerable way towards fulfilling this requirement, as its resistance is not constant but varies inversely as the applied potential. To make this clear, let me take an example. In the case above mentioned, in order to be sure that the full current would pass when a fault occurred, the iron grid resistance had to be kept down to 16·7 ohms, but with the carbon-powder type, as it has a negative temperature coefficient, this value can be increased to 23 ohms, this being the ohmic value with 5 800 volts on the terminals. When, however, there is no fault on the system, the potential across the resistance is that due to the potential between neutrals, and with this potential the ohmic value is increased to 69 ohms, i.e. three times as much. In the above case, by putting in carbon-powder resistances, the circulating current was reduced from 64 to 8 amperes.

Mr. J. M. Donaldson: I should like to refer to a condition which is not mentioned specifically in the paper, i.e. the case when two power stations are con-

nected not by a pure transmission line but by what I should call a distributor. In other words, the connection may be described as an extended busbar with a group of generators at either end. I believe this condition occurs quite frequently in practice, but I should not like to say that every such line must be used as a distributor, because the expense incurred in dealing with pressures of 20 000 or 30 000 volts in this country is very large. I am especially interested in this matter, because I am connected with the North Metropolitan Company, whose two main power stations at Brimsdown and Willesden have for some 15 years been electrically interconnected. These stations, however, were not run in parallel until about 3 years ago, and before this time the arrangement was not particularly convenient because load could be transferred only in portions, i.e. by transferring a rotary converter from one station to another. It was obviously desirable to run the power stations in parallel, because this rendered it possible to run the plant in the individual power stations more efficiently, i.e. more nearly at full load. I believe that this question of running plant load factor has a very considerable influence on the actual *running* costs, far more so, indeed, than the load factor of the supply. Another advantage is that one power station can assist the other in the event of trouble with steam or condensing water. On the other hand, if there is very serious trouble in one power station the whole network may be upset. I think the balance of advantage is in favour of this method, but we hesitated to adopt the system because we did not know how the machines would run in parallel. The physical conditions are rather unusual, because the nearest cable route between the power stations is over 15 miles long. We came to the conclusion that the limiting figure for parallel running was the ratio of the reactance to the resistance of the whole circuit. We worked out the case of a 6 000-kW machine running at each power station; we added the reactance, etc., of the machines, and we obtained a ratio of about 1·875, which has proved quite satisfactory. It must be pointed out, however, that with more units running this ratio is considerably reduced. I think that in this case a reactance is unnecessary for parallel running, but that it is desirable from the point of view of protecting the system generally. If such a reactance is employed it should be put near the centre of the system, because it does not have the same effect on the regulation as it would if it were placed at either end or both ends. Our method of running is to give one station control of the voltage by means of an automatic regulator which keeps the pressure at a constant predetermined value. The other station regulates the excitation so as to bring the power factor of the system to the value which it would have if that station were taking its share of the load. Another point which I should like to mention is in regard to the variation of voltage between two interconnected stations. In my opinion this variation is not necessary in the circumstances I have outlined, but for power stations which are interconnected by pure transmission lines I should much prefer to adjust independently the voltage sent or received. I should rule out the induction regulator, at least of the three-phase type, as the best means of effecting this variation, partly for reasons cited in the paper and partly because they are not made in this country. We have used these very largely for local work, but the three-phase regulator has an awkward phase-angle, although this difficulty can be overcome by using 3 single-phase regulators. The method which appeals to me most is not mentioned in the paper; it is due to Berry and is in effect a variation of the tapping system, and the regulation is effected on a little transformer at any pressure and voltage desired. It is somewhat complicated to install and is rather expensive, but it seems to me to overcome a difficulty which certainly will have to be faced to a much greater extent in the future in this country.

Mr. G. W. Partridge: I think that this subject might easily be divided into two parts. First there is the system in which the power stations are a great distance apart and very high pressures are employed. Then there are the dense areas such as London or Chicago, in which large generating stations are comparatively close to one another, and in which enormous short-circuit currents take place at any time when trouble arises. These two problems, to my mind, are entirely different and must be treated differently. In the case of long-distance transmission certain risks may be taken, but in the case of a condensed system such as I have referred to it is essential that the system should be so arranged that if anything goes wrong the load is automatically subdivided by means of special reactances and by special switches, so that a complete shut-down may be avoided. Some years ago I advocated that these generating stations should run on what I believe is now known as a synchronous busbar, i.e. the generators or groups of generators are connected through reactances to a separate busbar and kept running in parallel by means of this "synchronous bar," whereas outside the power station they are subdivided and run on separate groups or circuits, the idea being that in case of serious trouble the system automatically divides itself into separate groups. In the Deptford power station, which runs in parallel with the Greenwich power station, the load, as pointed out by the authors, is adjusted by means of the turbine governors, and the power factor by means of excitation. Our power factor varies from 85 to about 97 per cent, and no difficulty is experienced in running. A load of from 5 000 to 6 000 kW is transferred either way as and when required. With regard to automatic regulators, I am inclined to agree with Mr. Hunter that the induction regulator is the best, although very expensive. On the other hand, in running on extra-high-pressure systems, if the inductance is varied, particularly if the capacity current is large, trouble is liable to occur owing to pressure-rises. Many years ago we used the sort of automatic booster described by Mr. Donaldson, and we experienced the same trouble in taking it out of circuit as is described by the authors on page 290, in which they point out the difficulty of the main current in the series winding, being unopposed, magnetizing the core, thus causing an abnormal rise of pressure. In those days we did not realize this difficulty, and we burnt up one or two transformers before we dis-

covered the cause when endeavouring to switch booster transformers out of circuit.

Mr. A. R. Everest: I find the expression "power factor of the line" rather confusing; in reality it is the power factor of the transferred load at the supply end which is of importance. The paper clearly brings out one point of fundamental importance, viz. that if it is attempted to interconnect two stations excited to equal voltages the only exchange current which can flow is, so far as the supply station is concerned, a current which is leading in phase. If the station taking up the additional load can thus supply only leading current, obviously the lagging current component required for that portion of the load thus transferred must be carried somewhere else and give rise to exceptionally heavy lagging loads on the machine at the other end. To my mind that is the key of the authors' argument, as showing it is not practicable to transfer power with equal voltages, and that therefore some provision must be made for adjusting the voltages at the two ends in order to avoid this objectionable condition. The "synchronizing power of the line" is mentioned in the paper. It is difficult to conceive exactly what this is, and I should like to ask the authors whether they consider it possible to calculate the synchronizing power which will result with a tie line of known constants without a knowledge of the constants of the generators as well as of the transmission line itself. In the discussion the resistance and reactance of the line only have been referred to; I do not think that there is any reference to the internal constants of the generators, and a knowledge of these as well as of the line constants is essential before the synchronizing power can be determined for a given condition.

Mr. F. Fairley (*communicated*): I should be glad of some information as to the number and kilowatt capacity of the interconnecting cables required in relation to the kilowatt capacity of the power houses, and the load transfer between such stations; also an account of the difficulties, if any, experienced in operation. I have recently returned from America and the following notes of what is being done in that country may be of interest. American experience seems to show that interconnection does not in practice possess the difficulties which we have in the past been led to suppose. In America, interconnection is rather the rule than the exception; amongst other places where this system is employed may be mentioned the two power houses of the Duquesne Light and Power Company of Pittsburg, the Niagara Falls power group, the Buffalo General Electric Company's power station, and the power houses in Chicago, Detroit and New York. The operating staff of the Commonwealth Edison Co. of Chicago informed me that generally no trouble is experienced when operating their three power houses in parallel, except when serious breakdowns occur and two stations have to carry the bulk of the load. In Chicago the 25- and 60-period plant in each station operates independently (i.e. not through frequency-changer sets) and in parallel with similar plant in each station. Heavy tie lines (interconnectors) are used on both the 25- and 60-period systems with 4 to 6 per cent external reactances in series. The estimated peak load this winter on the Commonwealth Edison Company's system is 530 000 kW. Mr. Cato, the Electrical Superintendent of the Detroit Edison Co., told me, with regard to the interconnection of the Connors Creek and Delray power houses, that prior to last January both stations were run with all interconnecting cables between substations tied solidly in, each substation taking a supply from both main stations. Since last January, however, the two stations, which have a combined capacity of 278 000 kW, have been operating satisfactorily in parallel with only two cables as tie lines. The joint capacity of these cables at normal rating is only 12 000 kW, or 4·3 per cent of the capacity of the two power houses. I was informed that no external reactances are used on the tie lines or elsewhere on the Detroit system as they are found to be unnecessary. The circuit breakers on the two direct tie lines are set to operate a little higher than those on the outgoing feeders and, in the event of a fault or short-circuit on one of the feeders (several have occurred since the re-interconnection has been in use), only the switch on the faulty feeder opens, causing a momentary swing on the tie lines. This swing is, however, insufficient to cause a surge or other disturbance of any magnitude on the system. I understood from Mr. Cato that the primary reason which decided him to make this change in the high-tension network was to obviate the danger of both power houses feeding into a fault. It is claimed that the setting of the tie-line switches, i.e. about 25 000 kW, limits the amount of power which can be fed into a fault by both stations to the capacity of the smallest plant. At the time of my visit, 7 months' operating experience had substantiated this claim, and the new arrangement has proved to be entirely satisfactory in commercial service. The two tie lines are equipped with inverse-time overload relays, the other feeders on the system being equipped at both ends with a new type of cross-connected differential relay.

Messrs. L. Romero and **J. B. Palmer** (*in reply*): We are glad to find that Mr. Hunter is in general agreement with the principles which we have brought forward. We agree with his remarks on "phase swinging," which is the effect on the electrical conditions caused by the periodical acceleration and deceleration of the generating plant in one station relatively to the plant in the other station, as explained in the section of the paper dealing with synchronizing power. The operation of interconnected stations with equal station voltages and without boost in the line is such a simple and attractive proposition that we are of opinion that under specially favourable conditions it may find a field of application in spite of its disadvantages. With equal voltage transmission, as stated in the paper, it is possible, by making the ratio of the reactance to the resistance high, to make the power factor of transmission high also, thus minimizing the wattless component to be supplied by the receiving station. We admit, however, that the field of application of the "equal voltage" condition is likely to be very limited, and to that extent we are in agreement with Mr. Hunter's views. For interconnections involving the interchange of large amounts of power, we have no hesitation in saying that

the induction regulator is preferable to any other type, but our experience goes to show that there are many cases where the comparatively high cost of an induction regulator would not be justified. We know of installations where the load conditions are so steady that adjustment of voltage is seldom necessary, and the step-by-step regulator has in these cases been satisfactory. Mr. Hunter is undoubtedly correct in saying that many of the difficulties of power station interconnection would disappear if the interconnectors were laid out as network feeders rather than as interconnections between the busbars of power stations, but there are numerous cases where local peculiarities (such as the location of the power stations with respect to their networks) do not give much opportunity for the addition of load at points along the interconnector. The point Mr. Hunter makes is, however, very important, and engineers contemplating interconnection would do well to consider carefully, when fixing the route of the interconnector, the prospects of picking up load at intermediate points.

The use of interconnectors as distributors was also mentioned by Mr. Donaldson. The two extreme cases might be defined as follows :—

(1) The whole or the bulk of the load lies between the two power stations. In this case the problems discussed in the paper would not arise, as the two stations would simply feed into the network and not interchange power at all.

(2) The bulk of the load is located in the two areas surrounding the two power stations and a small load (relatively to the load transmitted between the two power stations) is tapped off the interconnector for isolated factories or villages *en route*. In this case the variation of voltage at points on the interconnector might be considerable when the direction of the flow of power was reversed, and special steps might have to be taken to give the consumers a constant voltage.

Between these two extreme cases there will obviously be a point where the connecting cables will cease to be a true interconnector for the transfer of power from one power station to the other in the sense discussed in the paper.

We share Mr. Hunter's preference for the arrangements of regulating apparatus where the boosting pressure is applied at both ends of the interconnector. The numerical example given in connection with Fig. 4, however, is for a case where a permanent boost is given by winding the transformers for different ratios; the transfer of power would not be reversible in these circumstances, and we take Mr. Hunter's remarks to apply to the general case covered by the diagram.

Mr. Clough's remarks generally confirm the statements and conclusions in the paper. We are inclined to agree that there is a good deal to be said for his arguments in favour of the use of imaginary quantities, as used by Dr. Steinmetz, in calculating the voltages and power factors. We have made a number of calculations since the reading of the paper, using both methods, and we still consider the formulæ given in the paper to be the simpler, but it is of course a matter of individual preference.

Mr. Brazil raised an important point in referring to the earthing of the generator neutrals of interconnected stations. We are of opinion that the Board of Trade Regulation which prohibits the earthing of a "circuit" in more than one place should be reviewed in the light of modern conditions. Experience in the United States, where "multiple earthing" is fairly general, goes to show that in the majority of cases there is no objection to it. Mr. Brazil's remarks on the methods of earthing, and the characteristics of resistances, etc., while very interesting, are rather outside the scope of the paper.

We are generally in agreement with Mr. Partridge's contribution. It is very interesting to find that the "synchronizing busbar" system of running, which is now being adopted extensively in the United States and this country, has been in use at Deptford for some years. The information Mr. Partridge gives with regard to the parallel operation of the Deptford and Greenwich power stations is most interesting. We believe that the distance between these stations is small, and that any power factor control required is apparently carried out by altering the excitation and busbar voltage at one or both stations.

In reply to Mr. Everest, the expression "power factor of the line" was used in the paper to distinguish the power factor of the load transmitted between two stations from the power factors of the loads on the station networks. The power factors of the transferred load at the two ends of the interconnecting line are the important quantities, and these are worked out in Appendix I and shown in Table 1. In replying to Mr. Hunter, we have already dealt with the point raised about transferring power at equal station voltages.

Our definition of the synchronizing power of the line, slightly amplified, is :—

> "The amount of additional power which will flow through the line (practically all of which will be available for synchronizing) when the phase angle between the station voltages is displaced by a definite angle from the stable angle necessary to transmit the energy forced through the line by the prime movers driving the generators."

We call it the synchronizing power of the line, because it has reference only to the line and is quite independent of the number, capacity, or internal constants of the generators and other synchronous plant. The point to be borne in mind is that, so long as the station busbar voltages remain constant, the synchronizing power which will flow between the two stations under any given set of load conditions will depend purely on the constants of the interconnector and the phase angle displacement between the two station voltages.

Mr. Donaldson refers to the ratio of the reactance to the resistance. For the reasons stated in our reply to Mr. Everest and in the paper, we are of opinion that, with constant station voltages, only the reactance and resistance of the line have to be considered in calculating the synchronizing power. For a given value of resistance the synchronizing power is a maximum when the

ratio of the reactance to the resistance is unity, but from the point of view of power factor regulation, when a fixed boost is employed, the power factor with varying load is improved by making the above ratio greater than unity. This is also the case when interconnecting at constant and equal voltages; the greater the ratio of the reactance to the resistance, the higher will be the mean (leading) power factor.

Mr. Fairley gives some very interesting information about interconnections on the very large systems of the Commonwealth Edison Company of Chicago, and of the Detroit Edison Company. This information seems to confirm the opinion expressed in the paper, that the adequacy of the synchronizing power of an interconnecting line does not depend directly on the capacity of the plant installed in the power stations.

A METHOD OF REGULATING THE VOLTAGES ON THE TWO SIDES OF A THREE-WIRE D.C. SYSTEM EQUALIZED BY STATIC BALANCERS.

By R. D. Archibald, Member.

(*Paper received 29th June, 1921; read before the* Dundee Sub-Centre *12th December, 1921, and before the* Irish Centre (Dublin), *10th February, 1922.*)

Summary.

The merits of the static balancer are compared with those of rotary balancers, the chief disadvantage of the former being that the voltage on the two sides of the three-wire system cannot be regulated without the aid of a mid-wire booster.

An arrangement is described whereby this disadvantage can be overcome by the use of tappings other than the central point of the winding of the balancer, rectifying the voltage between these tappings and the central point, and inserting the rectified E.M.F. into the side of the system the voltage of which it is required to raise.

The name "static balancer," as distinguished from "rotary balancer," is now commonly used to describe the method of balancing a three-wire direct-current system by connecting the neutral wire to the middle point of a single-phase or polyphase choking coil, the outer ends of which are connected through slip-rings to the armature of a direct-current machine placed across the outer wires of the system.

Although the static balancer gives a close regulation of voltage on a three-wire system, there are cases where it is desirable to be able not only to adjust the voltages on the two sides of the system, but to overbalance the voltage in favour of the side which is most heavily loaded. A mid-wire booster will perform these duties, but it involves the installation of a couple of rotary machines, together with starting gear, all of which would be out of the question in a small installation.

The static balancer has come into favour in small installations due to its efficiency, small cost, and sturdiness during a short-circuit. In large systems of distribution it is usual to connect the neutral to the middle point of one secondary winding of the transformer supplying the rotary converter, so that no direct-current magnetization shall occur in the transformer core. Although not an ideal arrangement, it works well in practice, and the low resistance of the transformer winding ensures that the difference in pressure between the two sides of the three-wire system shall be small when an out-of-balance current flows. On the other hand, supplementary rotating balancers are often used to compensate for the slight voltage-drops at different localities, and in this case the rotary balancer probably takes all or nearly all of the out-of-balance current, since a perfect balance implies that the static balancer is dealing with no neutral current. In this case the static balancer acts as a safety device during short-circuits, and ensures continuity of supply in cases where the rotary balancer alone might break down altogether. It would not, as a rule, be convenient to correct the balance of an outlying substation by means of a centrally-situated rotary balancer, and local means

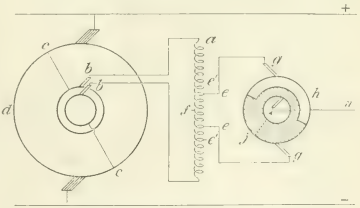


Fig. 1.—Method of voltage regulation on single-phase systems.

for regulating the voltages on the two sides of the three-wire system would be advantageous.

The method here described of regulating these voltages has been tried in the Electrical Laboratory of the Technical College, Dundee, and has been found to work quite satisfactorily. Briefly, it consists in the use of tappings at points other than the central point of the balancer windings, and the rectification of the voltage between these points and the central point. This rectified voltage is then applied to that side of the three-wire system which is most heavily loaded.

Fig. 1 shows the arrangement for single-phase, and

Fig. 2 for two-phase balancers. In Fig. 1, a is the winding of the static balancer, b, b are the brushes and slip-rings connected to the points c, c of the armature winding of the direct-current machine d, which is connected to the outers of the three-wire system. Tappings e, e, equidistant from the middle point f, are taken from the windings of the static balancer. These are connected to the brushes g, g which bear on the neutral wire n. The neutral is therefore alternately connected to one or other of the tappings e, e. This causes the potential of the neutral wire to pulsate with respect to that of the mid-point f of the balancer winding, so that the mean potential of t. neutral wire is either above or below that of f.

In Fig. 3 the potentials of the three wires o a three-wire system are plotted against time, and the pulsating

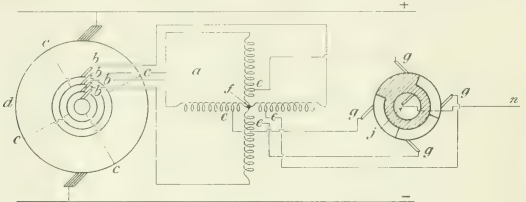


Fig. 2.—Method of voltage regulation on two-phase systems.

rectifying commutator h (shown diagrammatically) The commutator consists of the shaded or "active" part and the clear or "dummy" part which is insulated from the active part. As the commutator revolves, the shaded part connects the brushes g, g to the brush j alternately each half-revolution. With the number of segments shown, the speed of the commutator must be the same as that of a 2-pole alternator producing the

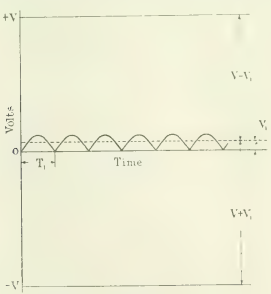


Fig. 3.—Showing the pulsating voltage on a three-wire system.

same frequency as that of the alternating current in the balancer. This is conveniently effected by driving the commutator by means of a chain or gearing from the shaft of the direct-current machine d or, as in this case, by fixing the commutator on to the end of the shaft and increasing the segments to suit the number of poles in d. That is to say, the number of segments would have to be increased in proportion to the number of pairs of poles in d. The brush j is connected to the

voltage is seen to be such that it decreases the voltage on the positive and increases it on the negative side. Assuming there is no load, V_1 is the average height of one pulsation, so that the average voltage on the positive side is $V - V_1$ and, on the negative side, $V + V_1$. The effective values will be slightly greater in each case. The result is that the effective voltage on the positive side is smaller than that on the negative, whilst on both sides is superposed a ripple, the wave-shape of which differs on either side of the mean, and the frequency of which is double that of the alternating current in the static balancer, one cycle being completed in time T_1 (Fig. 3). The wave-shape is shown as if the voltage were rectified instantaneously at the zero point. Actually, the brushes may require to be shifted forward slightly to overcome sparking, in which case the value of V_1 would be slightly smaller, due to a small part of the rectified voltage being used to assist

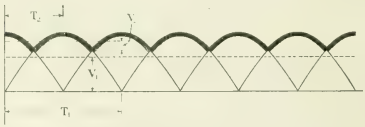


Fig. 4.—Showing the pulsating voltage with a two-phase arrangement.

commutation. The self-inductance per turn in a transformer is, however, comparatively low, so that the question of sparking is not a serious one. If a two-phase arrangement be adopted, as shown in Fig. 2, the pulsation of electromotive force is much reduced. The heavy-line curve in Fig. 4 shows the pulsating electromotive force in this case. Whereas the amplitude of the ripple in the single-phase case would be V_1, in the two-phase case it would be V_2, or less than

one-third, and, since the time of one complete cycle is now T_2 instead of T_1 (Fig. 4), the frequency is again doubled, and is now equal to four times that of the alternating current in the balancer. The chances of flickering occurring are therefore very much reduced.

Greater values of V_1 and V_2 are produced by switching to tappings e', e' (Fig. 1), more remote from the centre point. To change the rectified voltage from one side to the other the connections from e, e to g, g are changed over. Both voltage variation and change-over can be effected by shifting the brushes round the commutator, as it is found that with the low voltage

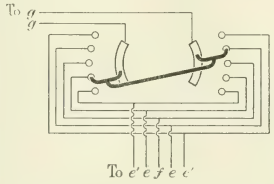


FIG. 5.—Switch for effecting voltage variation and change-over.

rectified there is a wide range of positions with sparkless commutation. Where this is not possible a switch for the purpose of changing the connections is shown in Fig. 5. In the horizontal position this switch connects the neutral to the mid-point f of the balancer winding. A clockwise movement of the switch will connect the brushes g, g to the tappings e, e and e', e' in one direction, and an anti-clockwise movement in the reverse direction. Where the static balancing is performed by means of a large transformer connected to a rotary converter it is not essential to tap the windings. A few turns of smaller section than the transformer secondary windings,

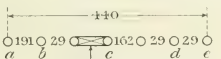


FIG. 6.—Arrangement of tappings on transformer.

wrapped round the yoke, will suffice, and, if the voltage per turn is too high to obtain convenient taps, the ends can be brought out and connected to a small choking-coil from which the required tappings can be obtained.

The tests were taken with a single-phase arrangement. A 25-kW, 4-pole rotary converter was used and was run at a speed of 1 500 r.p.m. from a direct-current supply at 400 volts. The choking-coil consisted of the high-tension winding of a 6-kW transformer, the normal voltage across the winding being 440 volts at 25 periods per second. The transformer had tappings as shown in Fig. 6, the numbers representing the voltages between tappings when a pressure of 440 volts was applied across the ends of the winding. The winding was first tested as an ordinary static balancer with the centre point c connected to the neutral, and the outer ends a, e, connected to the rotary converter. This gave a difference of 18 volts between the positive and negative sides with a neutral current of 25 amperes. With the rectifier in circuit the tappings b, c were connected to the rectifier and, in order that b and c should be equidistant from the central point, the rotary converter was connected to the ends a, d. The voltage between the tappings b, c was then just over 20 volts, and this is the amount which the rectifier supplies to the neutral and by which the two sides will differ.

The difference in voltage between the two sides was found to be 20 volts with no neutral current flowing, the negative side being the higher. As the negative side was loaded up, this potential difference decreased at a rate corresponding to a straight-line characteristic when plotted against the neutral current,

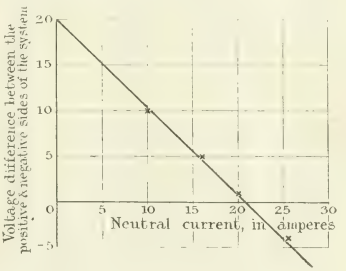


FIG. 7.—Variation of voltage difference with neutral current.

as shown in Fig. 7. No flicker was observable at 50 periods, but a faint flicker was observed at 29·5 periods. A section of the secondary winding representing 11 volts was placed in the centre of the primary and connected to the rectifier, but the flicker was still observable. Tests were then taken as an ordinary static balancer, and it was found that a faint flicker was still just observable at this frequency. The flicker could not, therefore, be attributed entirely to the rectifier, although it seemed a little more pronounced when the rectifier was in circuit.

The rectifier was improvised from two experimental slip-rings on the rotary shaft (used ordinarily for a search coil), by screwing sheet-brass segments on to the top of the rings in such a way that each segment was in metallic contact with one ring and overlapped, but was insulated from, the other. Part of each ring was available for the brushes g, g, and the brush j bore on the segments. This is the inverse of the arrangement shown in Fig. 1. The brush j was of low resistance and quite sparkless running was obtained.

The author is of the opinion that the rotary form of

rectifier has not of late received the attention it deserves, and that there are many cases where it might be applied, e.g. when batteries are inconvenient as a source of low-pressure direct current and pulsation of the current is of no consequence. The arrangement here described is one that could be easily applied to any existing direct-current machine. Even at high voltages it, seems as if it could be developed still further, in the present state of our knowledge regarding the causes and prevention of sparking.

APPENDIX.

Results of Tests.

D.C. Side of Rotary Converter			Three-wire System					
			Volts		Amperes			
Volts	Amperes	~	+	−	+	−	Neutral Current	Remarks
428	4·5	50	214	214	—	—	—	With neutral connected to centre point of winding
423	15	50	220	203	—	25	25	
428	4	50	224	204	—	—	—	With neutral connected to rectifier
426	8·5	50	218	208	—	10	10	
425	11	50	215	210	—	15·5	15·5	
425	13	50	212	213	—	20	20	
424	16	50	210	214	—	25·5	25·5	

Discussion before the Irish Centre, at Dublin, 10 February, 1922.

Mr. G. F. Pilditch: I think that the combination of a static balancer with the rotary rectifier suggested by the author robs the static balancer of what I always considered to be its most valuable property, i.e. that of being absolutely automatic in its operation, without the necessity for any moving parts. I have myself had no experience with static balancers, as two machines connected in series are used for the 3-wire supply in my station. This arrangement has proved most satisfactory, and I doubt whether the author's arrangement with its rotating mechanism and special switchgear would be superior to it. I consider the greater flexibility obtained by the use of pairs of generators to be worth the extra cost in sets up to 500 kW capacity. I should be glad to know how the author's arrangement would work when attached to several machines working in parallel, and with what percentage of out-of-balance current it could deal.

Mr. C. P. C. Cummins: It is very important to get a clear insight into the operation of a static balancer, in order to appreciate fully the author's rotary rectifier, which I consider to be a most interesting addition to the static balancer. I look forward to its giving considerable assistance in small stations where a number of 3-wire feeders enter the station, on each of which the out-of-balance current may be different both in magnitude and in sign. In this connection I should like to know whether any serious difficulty would arise if the tappings from the balancer coil connected to one generator were wired to as many switches as there are feeders, each switch being connected through a separate rotary rectifier to the mid-wire of one set of feeders. If this could be done the rotary rectifier suggests great possibilities for small stations, as it would enable different out-of-balance currents to be dealt with fairly easily, and to some extent the positive out-of-balance current on one set of feeders could be made to compensate for the negative out-of-balance current on another set of feeders, without interconnecting the feeders at their far ends. Referring to the smoothing-out of the inequalities in the curve of voltage when a two-phase or, as I would prefer to call it, a four-phase arrangement is adopted, and in connection with the last paragraph in the paper, I should like to know whether with an arrangement consisting of 6 or more phases (when the voltage curve would be practically a straight line) the author considers it would be feasible for station engineers to deal with the charging of electric battery vehicles.

Mr. E. C. Handcock: In Ireland a large percentage of the electric lighting plants are of small capacity, and these balancers are not used to anything like the degree to which their simplicity and low cost, both capital and operating, entitle them. As they consist of only an auto-transformer connected to the generator by means of slip-rings the losses are small, comprising only the power required to magnetize the core of the static balancer, and the ohmic losses caused by the neutral current passing through the windings; whereas the rotary balancer entails a separate set with control gear and a duplicate set to ensure continuity of supply. This rotary balancer must be kept running continuously. It will at once be seen that for small town lighting plants the advantage is very much in favour of static balancers, particularly as they are usually rated to carry continuously an out-of-balance current corre-

sponding to 25 per cent of the generator rating, which is ample for the conditions in question. With such an out-of-balance current the voltage of one side will fall and the other will increase approximately by 1 to ½ per cent of the mean voltage. I would strongly advocate the use of 440-volt, 3-wire generators, as I have frequently seen cases where 220-volt, 2-wire generators have been installed in the first instance and then in a few years when a pressure of 220 volts has been outgrown have had to be replaced by 440-volt machines, or else new overhead mains have been necessary, both involving abnormal expenditure. I believe that electrical development in this country is about to increase rapidly, and there is no reason why such a mistake as I have instanced should be made when the static balancer supplies such a cheap and economical method of giving 440 volts across the outers and 220 volts for lighting on a 3-wire system.

Mr. W. Tatlow: I am of the opinion that the static balancer makes the 3-wire system available for the lighting of comparatively small villages. There are many such in Ireland where the houses are for the most part built along a single long street, and where one or two relatively larger loads, due to public institutions, e.g. a workhouse or a convent, are situated at some distance from the village. The author's device in such cases would be of assistance in regulating the pressures at the end of exceptionally long feeders. I fear that trouble is likely to arise from sparking at the commutators under ordinary working conditions, as rectifiers which were used in connection with arc lighting in the early days sparked excessively.

Mr. R. D. Archibald (*in reply, communicated*): With reference to Mr. Pilditch's remarks, when several machines are working in parallel only one rectifier need be used in small stations as it can be made detachable. If each machine has a rectifier attached there is no difficulty in parallel running, but single-phase rectifiers might, in certain cases, require a damping coil to prevent local alternating currents. Such coils would not be required with synchronized machines such as rotary converters. Static balancers usually run much below the maximum permissible temperature owing to the regulation of voltage specified. The attachment of the rectifier enables the balancer to deal with much greater out-of-balance currents, as the voltage can be adjusted on the two sides of the 3-wire system.

In reply to Mr. Cummins, the use of a rectifier on each feeder from a common balancer involves no difficulties and saves the cost of the cable used for interconnection of feeders, which in some cases is quite a considerable item. With the arrangement suggested, 12-volt accummulators could easily be charged, with a great saving of energy, and I have charged cells even with the single-phase arrangement at 50 frequency. The charging of electric battery vehicles involves much higher voltages, and the commutation might be difficult.

Mr. Tatlow compares the rectifier with the arc lighting dynamo used many years ago, but the practical conditions are very different. In this case the rectifier deals with very low voltages, and that is the reason why it does not spark.

SINGLE- AND THREE-PHASE ALTERNATING-CURRENT COMMUTATOR MOTORS WITH SERIES AND SHUNT CHARACTERISTICS.

By Stanley Parker Smith, D.Sc., Member.

(Introductory Notes to a Lecture delivered at The Institution 5th January, 1922, before the North-Eastern Centre 28th November, before the Tees-side Sub-Centre 29th November, and before the Liverpool Sub-Centre 12th December, 1921, also before the North Midland Centre 17th January, and before the South Midland Centre 1st February, 1922.)

Introduction.

Owing to the rapid growth of alternating-current networks, there is an increasing demand for alternating-current motors.

Among the chief demands made on alternating-current motors are:—

High power factor;
Large starting torque; and
Economical speed regulation.

(1) Non-commutator Types.

These include the synchronous motor and the induction motor.

(*a*) *Synchronous motor.*—By winding the rotor as for an induction motor, the machine can exert a powerful starting torque. A similar result can be obtained with the salient-pole construction by arranging the damping winding so that the cross-flux at starting becomes approximately equal to the main flux. By adjustment of the exciting current the power factor can be varied at will. A supply of direct current is necessary, and speed control is impracticable. This type is seldom used on single-phase supply.

(*b*) *Induction motor.*—None of the above requirements is feasible with single-phase induction motors, so that an alternative solution becomes essential.

Polyphase induction motors can be made to satisfy these demands, and therefore become active competitors with commutator motors.

Power-factor rectification is possible by means of a phase advancer of either the revolving or vibratory type. Here, again, a commutator appears to be essential.

A large starting torque merely demands that the power factor shall be kept high during starting, but the power taken from the mains is proportional to the torque and not to the output.

Economical speed variation of a single machine entails a change in the number of poles. This can be achieved by regrouping the coils or the phases, or by varying the phase angle (as in Creedy's method), or by cascade devices (as in Hunt's and Creedy's methods). The addition of a second, or cascade, motor introduces further possibilities.

By these means, multi-speed motors can be made to give 2, 3, 4, 5 or 6 constant speeds (shunt characteristics); but in several cases at the expense of high power factor and large starting torque. Further, gradual or continuous economical speed variation is impracticable.

(2) Commutator Motors.

The fact that what takes place in the conductors between them is always reproduced at the commutator brushes, independently of the sense or speed of rotation, renders it possible to connect the field and armature windings in series or in parallel, although inductive effects may entail modifications when alternating current is used.

In principle, then, the commutator motor—the action of which is independent of the speed—is eminently adapted for economical speed control and large starting torque, while in many cases a phase advancement can be obtained in addition.

Considering, for simplicity, the direct-current motor, where the use of a steady flux results in a continuous pressure between the commutator brushes, the speed is proportional to

$$\frac{\text{supply voltage} - \text{pressure-drop}}{\text{flux}}$$

The torque depends on the product of the armature current and flux.

Ignoring speed regulation by series resistance as uneconomical, it follows that the speed can be controlled by varying either the voltage or the field.

With a single machine, voltage control is impracticable with direct current, but practicable with alternating current, because a variable-ratio transformer or other device can be used.

With *field control*, the only economical method possible with a single direct-current motor, the torque varies inversely as the speed, assuming constant armature current; so that the output remains constant over the whole speed-range. Consequently, a variable-speed direct-current motor must be designed for the full output at the lowest speed, while at all higher speeds the material cannot be efficiently utilized.

With *voltage control*, which is possible with alternating-current motors, both field and armature current can be kept constant over the whole speed-range. Therefore, a constant torque is maintained, and the output is consequently proportional to the speed. This not only enables the material to be fully utilized over the whole working range, but corresponds more closely to the load characteristics of the majority of drives.

For example, for a speed-range of 1 : 3, a motor with field control would give, say, only 10 h.p. over the whole range, whereas a motor with voltage control would give 10 h.p. at the lowest speed and 30 h.p. at the highest speed.

(3) Alternating-current Commutator Motors.

From a practical point of view, the alternating-current commutator motors unite most of the drawbacks of the direct-current motor with those of the induction motor. In addition, a worse evil, the transformer E.M.F. induced in the coils being short-circuited by the brushes becomes one of the predominant factors in the design. From all these condinous variations which have flooded technical and patents literature during the last generation have been practically ignored. Further, this is not the proper occasion to refer to the individuals and the firms who have developed the several types or improvements.

As a matter of historical interest in connection with the original inventors of these machines, it may be said that the first mention of the fact that the

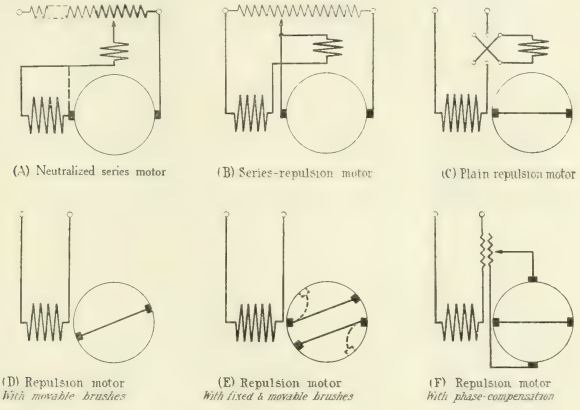


Fig. 1.—Single-phase motors with series characteristics.

siderations, the air-gap has to be kept short, the armature reaction has to be neutralized, and a low commutator voltage has to be employed, sometimes at the cost of a transformer.

The success attained in the development of commercial machines of numerous types represents one of the most signal achievements in the design of electrical machines.

Figs. 1 to 5 give examples of types which have attained practical importance, but no attempt at completion has been made, while the multitu-series motor, when laminated, could work with alternating current, appears to have been made by Alexander Siemens in 1884, in a discussion at a meeting of the Society of Telegraph Engineers; while the polyphase commutator motor was patented by Ernest Wilson in 1888 (E.P. 18 525). About the same time Wightman in America discovered rotor excitation, and, in 1898, Ll. B. Atkinson, in his paper on "The Theory, Design and Working of Alternate-current Motors" before the Institution of Civil Engineers, showed how the single-phase commutator motor could be made to

yield a shunt characteristic. The invention of the induction motor by Ferraris and by Tesla in 1885–86, and its much more rapid development, afford an insight into the difficulties associated with the development of alternating-current commutator motors.

(4) Single-phase Commutator Motors.

(i) With Series Characteristics.

Some of the chief types are illustrated in Fig. 1. The more rapid development of these types is attributable to two causes—their relative simplicity, and with a weak field and a strong armature magneto-motive force, by working well above synchronous speed, and by reducing inductive effects. On Continental single-phase railways, inductive effects are reduced by adopting a frequency of $16\frac{2}{3}$ periods per second. The neutralizing winding may be joined in series with the armature winding, or it may be short-circuited on itself. These motors have been built for outputs up to 3 000 h.p., while motors for 500 h.p. are quite common. About 40 to 80 h.p. per pole may be considered to be good design for large motors.

(B) In the *series-repulsion* (or doubly-fed) types,

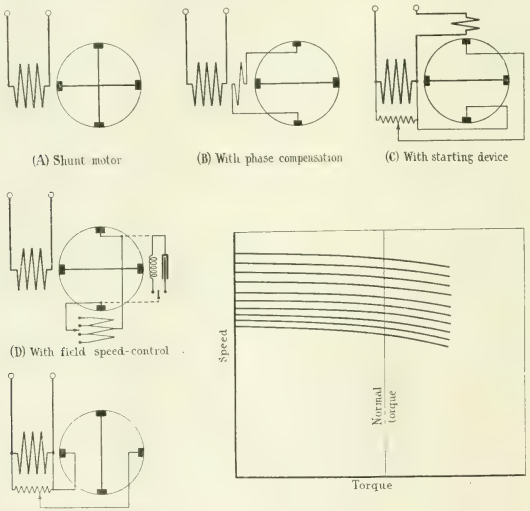


Fig. 2.—Single-phase shunt motors.

the incentive afforded by the prospects of railway electrification.

(A) The *neutralized series motor* has ousted all other types as a single-phase traction motor. For this work it is usual to neutralize the transformer E.M.F. in the short-circuited coil, by means of a rotational E.M.F. induced by the flux produced by an interpole winding shunted by a resistance and excited by the main current. This gives the motor a very wide speed-range. The speed is controlled from rest by means of a variable-ratio transformer, a transformer being also necessary for reducing the supply voltage to the motor voltage. High power factor is obtained by designing the motor power is supplied to both stator and rotor. Feeding via the stator is effected by the creation of a transformer flux (compare the action of the induction motor) along the brush axis. By reducing the ratio of the stator pressure to the rotor pressure as the speed rises, an approximate neutralization of the transformer E.M.F. in the short-circuited coils can be obtained. However, this type has practically given place to type (A).

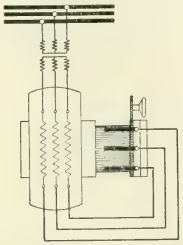
(C) In the *plain repulsion motor* the whole of the power is transferred inductively to the rotor, while the rotor voltage can be fixed independently of the stator voltage, so that no transformer is needed. At synchronous speed the transformer flux is correct for

neutralizing the inductive effects of the exciting flux on the short-circuited coils, so that the commutation conditions become similar to those in a direct-current machine. At other speeds, however, the magnitude of this flux is not correct for this purpose. This effect is particularly bad at hyper-synchronous speeds, and the net result is that all motors of the repulsion type are ill-suited for wide speed-ranges. The repulsion motor has a series characteristic because the exciting flux is produced by the main current.

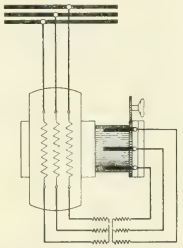
(D) Combining the two stator windings in (C), the movable set, the brush shift is doubled, so that much finer speed regulation can be obtained. In addition to this refinement, no flux embraces the short-circuited coils when the brushes are in the neutral position.

Though not suitable for large variable-speed traction motors, the types in (C), (D) and (E) are admirably adapted for small and medium outputs for industrial purposes, with speed-ranges varying roughly from standstill to about 30 per cent above synchronism.

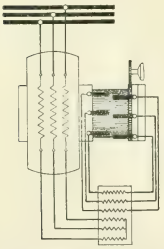
(F) *Phase compensation* is obtained by rotor excitation. These motors were used on the original electric



(A) With main transformer



(B) With rotor transformer



(C) With fixed & movable brushes

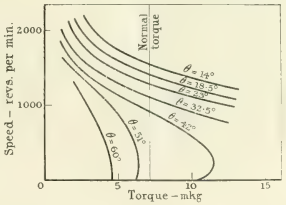


FIG. 3.—Three-phase series commutator motors.

common *repulsion motor with movable brushes* is obtained. The brushes are in the short-circuited position when the brush axis coincides with the axis of the stator winding; and in the neutral position when the brush axis is perpendicular thereto. In both positions the torque is zero. Starting with the brushes in the neutral position, no starter is required. The line voltage is applied to the stator winding, and the motor begins to revolve in the opposite direction to that in which the brushes are moved. Here, then, both transformer and starter can be dispensed with.

(E) By splitting the brushes into a fixed set and a rolling stock of the Brighton Railway, being practically the only type available at that time. The motor suffers, however, from the necessity of working in the neighbourhood of synchronous speed, while the superiority of type (A) has ousted it, along with other competitors, from traction work.

(ii) With Shunt Characteristics.

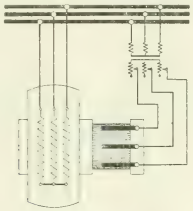
These are shown in Fig. 2. The shunt motor needs two sets of brushes, the main and the exciting brushes. The activities of inventors have been even greater in connection with shunt types than with series types.

(A) The *plain shunt motor* is decidedly inferior to the single-phase induction motor, for, in addition to possessing no starting torque, both efficiency and power factor are lower, and the motor runs merely at one speed, i.e. synchronism.

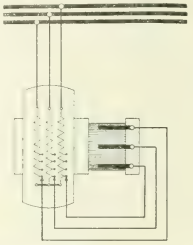
Some methods of overcoming these drawbacks are illustrated in Fig. 2.

(B) *Phase correction* is obtained by injecting a fraction of the applied pressure into the exciting circuit.

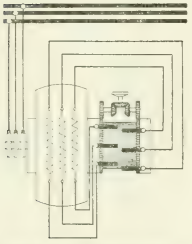
(C) *A large starting torque* is obtained by letting the motor run up to speed as a repulsion motor.



(A) With rotor transformer



(B) With stator tappings



(C) With double movable brushes

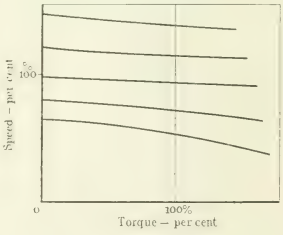


FIG. 4.—Three-phase shunt commutator motors.

The machine can then be made to run as a single-phase induction motor, but it is becoming common to combine the devices in (B) and (C) in order to obtain a constant-speed single-phase motor with high power factor and large starting torque.

(D) *Speed regulation* of the shunt motor is obtained by varying the exciting flux—an inductance being used to raise the speed, and a capacity to lower it; or an auxiliary winding can be employed for this purpose.

(E) In the doubly-fed type the speed is varied by regulating the pressure applied to the brushes in the transformer axis. This motor, the series-repulsion motor and the three-phase commutator types belong to the general class of electrical machines in which energy is supplied to both stator and rotor, the power relations being definitely associated with synchronous speed.

(5) THREE-PHASE COMMUTATOR MOTORS.

The addition of the commutator to the rotor of the three-phase induction motor raises the frequency of the slip energy to the frequency of supply, and thereby enables this energy to be taken from, or returned to, the supply network, according to whether the speed is above or below synchronism. Thus, the motor range is not confined to sub-synchronous speeds, as in the induction motor. The limitation imposed on the speed-range of the three-phase commutator motor by the transformer E.M.F. induced in the short-circuited coils is similar in effect to that imposed on the repulsion motor, while the rotor is wound for equally low voltages.

(i) WITH SERIES CHARACTERISTICS.

The common method of controlling the speed of the three-phase series motor is by shifting the brushes. The direction of rotation depends on which side of

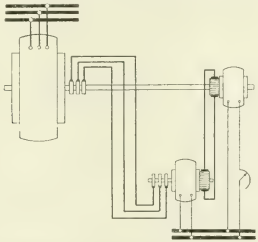
the short-circuit axis the brushes lie, and is independent of the sense of the rotary field. When such a motor, with a fixed ratio of stator to rotor turns, is designed for a high power factor, instability occurs at low speeds, as shown by the characteristic curves in Fig. 3. It is usually necessary to provide a transformer to obtain the low rotor voltage.

(A) A *main transformer*, rated for the full power of the motor, is usually necessary only for severe conditions.

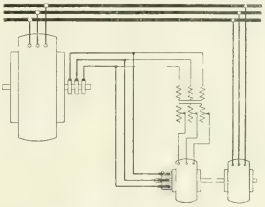
(B) A *rotor transformer*, rated for the slip power only, is all that is needed for many cases. By arranging that this transformer becomes saturated when the brushes are rocked through 180 degrees to pass from sub-synchronous to hyper-synchronous speed. The connections are shown in Fig. 4.

(A) A *variable-ratio rotor transformer*, capable of transmitting the slip power to or from the commutator brushes, fixes the speed at which the motor runs. A special connection can be used for altering the phase of the transformer voltage in order to raise the power factor.

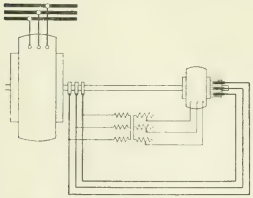
(B) It is sometimes possible to obtain the desired rotor pressure by taking tappings off the stator windings.



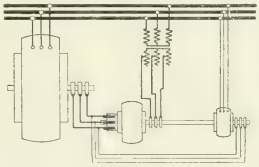
(A) With rotary-converter & coupled D.C. motor



(B) With 3-ph. commutator motor & induction generator



(C) With coupled 3 ph. commutator motor



(D) With frequency changer

FIG. 5.—Variable-speed sets.

rotor voltage attains a certain value, i.e. when a certain speed is reached, racing can be prevented.

(C) Where stability over the whole speed-range and a high power factor are needed, the ratio of the stator to the rotor turns can be decreased, as the speed rises, by one-half of the brushes being fixed and the other half movable.

Just as, for general purposes, the repulsion motor is the simplest type of single-phase commutator motor, so the three-phase series motor is the simplest type of three-phase commutator motor.

(ii) WITH SHUNT CHARACTERISTICS.

The speed of the three-phase shunt motor is varied by supplying a pressure to the rotor brushes, and the

(C) Where gradual speed control is required, the brushes can be arranged in two equal sets, both being movable and connected to the separate stator phases. Power is supplied through slip-rings to the rotor, while a special regulating winding may be employed as the commutator winding. Every brush position corresponds to a definite pressure and, therefore, to a definite speed.

In the previous types of three-phase shunt motor referred to, and in the three-phase series motors, the transformer E.M.F. becomes zero at synchronism, but in the present machine this E.M.F. remains the same at all speeds, because the frequency of the current in the rotor winding is always that of the supply.

In this respect the motor is similar to the single-

phase series motor; but in the latter the transformer E.M.F. can be neutralized, whereas in the former it cannot be.

It is further seen that the relative motion between the revolving field and the rotor is constant, and that this field is carried round by the rotor in such a manner that at synchronism the frequency of the E.M.F. induced in the stator winding is zero.

By starting from the neutral position a starter can be dispensed with, while phase compensation is obtained by shifting the two sets of brushes unequally.

The direction of rotation of three-phase shunt motors is changed as in an induction motor, i.e. by reversing two stator leads.

(6) Variable-speed Sets.

Assuming from 15 to 20 h.p. per pole to be the desirable limit for the output of a three-phase commutator motor, it is seen that such motors cannot well be built for outputs above 300 to 500 h.p. In many cases, however, it is only desired to utilize the slip power of a large induction motor having a limited speed-range. The three-phase commutator motor is well suited to fulfil these conditions, though it is possibly unsuited for the whole power at supply frequency. Various ways of utilizing the slip power are shown in Fig. 5. In many cases, phase compensation in the main motor is also aimed at. When the auxiliary motor is mechanically coupled to the main motor, the drive is suitable for constant output over the whole speed-range; otherwise it is suitable for constant torque. The rotary-converter set in (A) has been included on account of its importance. Whenever possible, it is desirable to arrange that synchronous speed shall be in the middle of the speed-range, for in this case the auxiliary machines have to be rated for only half the output that would be necessary if synchronous speed were the upper limit of the speed-range.

The lecturer is greatly indebted to Mr. J. W. Sims, Associate Member, also to Messrs. M. G. Say, B.Sc., and R. E. Hopkins, B.Sc., post-graduate students at the City and Guilds (Engineering) College, for their assistance in connection with the diagrams and experiments.

Discussion at The Institution, 5 January, 1922.

Mr. F. Creedy: The fundamental difficulty in practice with the machines described by the author is that a sufficient number of users will not pay the price which must be demanded in order to supply satisfactory apparatus. For instance, in the printed copy of the Lecture, circuit-changes are indicated by an arrow-head moving past a number of dots. This conceals very serious switchgear problems, and these, together with the problems which the motor itself involves, are among the chief reasons why these machines have been so heavily handicapped. These difficulties are minimized in the case of commutator machines operating in the neighbourhood of synchronous speed, i.e. constant-speed machines having a shunt characteristic. These machines are analogous in many ways to direct-current shunt machines, and have exactly the same commutating characteristics as the latter, the sparking being entirely due to reactance voltage in the ordinary sense of the term; consequently the rotor voltage may be very much higher and the commutator losses very much reduced as compared with those occurring in the variable-speed type. Such a machine finds its chief application on single-phase circuits where the importance of starting torque, in addition to the phase compensation possible when a commutator is used, makes the commutator machine far superior to all other types. Another reason for the low state of development of the commutator machine is the vicious circle due to the fact that until large numbers of machines are built the designer does not get adequate experience, and hence his early machines are so expensive as to discourage the building of the later ones. Owing to the active demand on industrial single-phase circuits, this difficulty has been overcome in this case, and machines of a really commercial pattern comparable in every way with direct-current or polyphase motors are now designed. Fig. A summarizes their qualities as shortly as possible. The upper curves show the efficiency of a single-phase motor as compared with that of a direct-current motor. It will be seen that in the small sizes, say of about 5 h.p., the efficiency of the single-phase

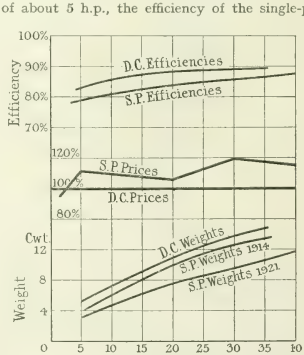


Fig. A.

motor is about 5 per cent below that of the direct-current motor, while in the larger sizes, of about 20 to 25 h.p., the difference is only about 3 per cent. These machines are for use on standard commercial 50-period circuits. In the lower curves are shown the weights of direct-current motors and single-phase

motors. It will be seen that the weight of the direct-current motor exceeds that of the older design of single-phase motor by about 10 per cent throughout the range shown, while the weight of a modern design of single-phase motor is only about two-thirds that of the direct-current motor. The middle curve shows the ratio of cost of this machine, the direct-current price being taken as 100 per cent. It will be seen that up to 25 h.p. the cost of the commutator type is only from 4 to 10 per cent higher than that of the direct-current motor. Above that size it is a little higher. It is about the same as that of a single-phase induction motor throughout the range.

I will show a lantern slide of a Parkinson motor-generator set of about 70 h.p. The reduced size of the single-phase motor, as compared with that of the direct-current generator, is very marked. The fundamental reason for the difficulty found in designing all such machines is the transformer E.M.F. induced in the coils short-circuited by the brushes, this voltage being proportional to the difference between the speed of the machine and synchronous speed in the case of a revolving-field motor. If we limit this voltage to a permissible value, only very low voltages can be employed on the commutator if any considerable variation of speed from synchronism is required, even if we ignore starting difficulties, as may be done with some classes of industrial machine. There is only one way of limiting the volts per bar to a permissible value, i.e. to keep the commutator voltage extremely low, thus involving a very large commutator. Again, in machines of quite moderate size the one-turn multiple rotor winding becomes essential and this places a definite limit upon the permissible flux per pole, owing to the conditions of good commutation. It therefore becomes necessary to make machines of large horse-power operate at very low speed, in order to keep the flux per pole within permissible limits. The chief drawback of the large commutator is perhaps not so much its cost as the losses which occur in it. These losses may cause a reduction of efficiency in a machine of wide speed-range where the commutator voltage must be low, of as much as 10 per cent below that of an induction machine possessing no commutator. It is quite easy to design an induction motor of only 10 h.p. to have an efficiency of about 90 per cent. To obtain such an efficiency in a 10-h.p. commutator machine arranged with a speed-range of, say, 2 to 1, is practically impossible and, in order to attain such figures, we should have to put into the machine a large amount of copper and iron, so as to reduce the losses in the motor itself in order to offset those occurring at the commutator. These considerations are fundamental and, while some improvement might be brought about by the use of commutating poles, until some invention is made eliminating this transformer E.M.F. and permitting us to operate our commutators at, say, 400 volts as is done in d.c. machines, this handicap must remain. The only known means of escape consists in the reduction of frequency, the size of commutator being directly proportional to the frequency. These are some of the reasons why, after a good deal of experimenting on these machines, I have come to the conclusion that the machine operating in the neighbourhood of synchronous speed has the greatest future, because of the non-existence of the transformer voltage. The commutator voltage must be kept relatively low on a variable-speed machine. In machines of under 100 h.p. the commutator voltage can seldom exceed 100 volts for 50 periods. When the machine operates near synchronism that voltage can be at least doubled for the same horse-power, and the commutator size can be halved. Since the reduction of efficiency as compared with the direct-current machine is due entirely to commutator losses, by halving the size of the commutator we halve the commutator losses, and therefore we raise the efficiency to quite a commercial figure. For this reason I feel some doubt about the applicability of the commutator machine to variable-speed machines on 50-period circuits. I cannot altogether let the author's strictures on English firms and engineers pass, because I think that they share my view. If they have not

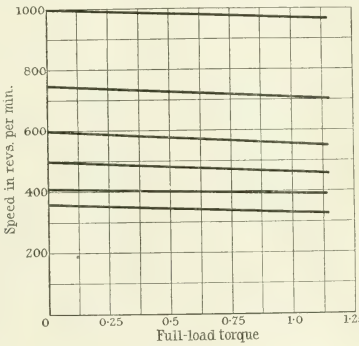


FIG. B.

developed these commutator machines, it is because they have been engaged on developing something else. I would point out in passing that the cascade machine is purely a British invention and has been developed entirely in this country. I am far from agreeing with the author that the commutator machine is the worst of all machines from the practical point of view and that it has all the drawbacks of the direct-current and induction motors combined. I admit that it has the drawbacks already referred to, and those drawbacks we are not entitled to incur if there is any way of dispensing with them. As a result of the considerations already mentioned, investigators have devoted a great deal of attention to the development of the induction motor along natural lines instead of trying to imitate the direct-current motor. By this means we preserve all its natural advantages, the chief of which is the absence of the commutator and commutator losses, which enables us to attain a

very high efficiency combined with an exceedingly robust construction suited to the roughest and heaviest work. There are two natural methods of varying the speed of an induction motor, viz. by changing the poles and by cascade operation. I shall now point out some of the salient characteristics of such machines. These are shown in Fig. B, which gives the speed/torque characteristics of a 6-speed motor of the induction type. I think that this figure speaks for itself and I would ask operating engineers to consider carefully whether the advantage of a gradual speed-change is so great as to justify the greatly increased prime cost and the cost of upkeep of the variable-speed motor of the commutator type when compared with a multi-speed motor giving these speed/torque curves. For instance, assume we wish to drive a boring mill at variable speeds, the speed of the table giving the best result being 20 r.p.m. We can, of course, get this speed with the gradual speed adjustment, but with the multi-speed motor we cannot get 20 r.p.m., but either 19 or 21 r.p.m. Is this difference worth troubling

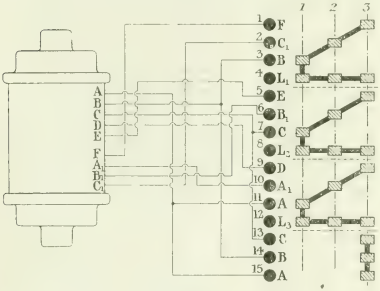


FIG. C.

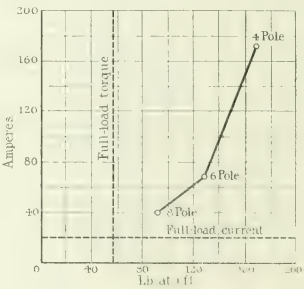


FIG. D.

about? In the majority of cases it certainly is not, although there are a few cases, of which the paper mill is probably one, in which an absolutely gradual change is essential. Machines have occasionally been built for two numbers of poles having two distinct windings, and these have produced a feeling that such machines are highly unsatisfactory, being small in output, poor in efficiency and having high temperature-rises. Suggestions have also been made in several quarters for re-connecting a single winding for a multiplicity of numbers of poles on, for instance, a three-phase circuit, and these have resulted in very complex connection diagrams. In the more up-to-date methods only one winding is used, and thus the whole of the copper is active on each number of poles, just as in the standard type of motor. The complexity of inter-connections is avoided by supplying the motor through a small auto-transformer, the function of which may be said to be that of adapting the current to the winding in cases where the winding cannot be adapted to the current, for instance, to a three-phase supply from the mains. The author has already described the principle of these motors, namely the changing of the number of poles by varying the phase between adjacent coils, and I shall therefore confine myself to describing the practical circuits employed for 3-, 4- and 5-speed motors, and some of the characteristics of the machines so produced. For 3-speed motors it is possible to avoid the use of a transformer altogether. Fig. C shows the circuit of a 3-speed motor, from which we see that in addition to the motor itself a controller requiring 15 fingers is required. For a 5-speed motor a phase transformer is required in addition. At first sight the use of a phase transformer may seem to add considerably to the cost, but it should be pointed out that the capacity of such a transformer is only from 18 to 20 per cent that of the motor, and hence it does not give rise to any very considerable expense. In small sizes it is often made of the air-cooled type. Comparing such a motor and its auxiliary apparatus with the polyphase variable-speed motor described in the paper we see that the commutator motor has a large commutator and brush-gear giving rise to losses throughout the running period and requiring a certain amount of upkeep. These are entirely absent in the multi-speed motor. By the use of these auxiliaries we do not, except in one particular type which has its own difficulties, eliminate the need for external control apparatus; on the contrary, just as in the case of the multi-speed motor, we have a controller and a transformer to vary the commutator voltage. This transformer will frequently be much larger than that required by the multi-speed motor, since a motor departing 30 per cent from synchronism requires a transformer of 30 per cent the motor capacity, and so on. A motor having a wide speed-range will therefore require a larger voltage transformer than the multi-speed phase transformer. Two questions will at once suggest themselves in connection with the application of multi-speed motors to many classes of drive, viz. (1) What starting torque are they capable of? and (2) Is it possible to change from one speed to the next without shock? As regards starting torque, it may

be pointed out that a multi-speed polyphase squirrel-cage motor is capable of much superior starting to a single-speed squirrel-cage motor. This was pointed out when squirrel-cage motors with more than one stator winding were used to drive the Simplon Tunnel locomotives. It is further emphasized in Fig. D, in which is shown starting torque plotted against starting current for a small 4-, 6- and 8-pole motor. It will be seen that with the 8-pole connection the machine gives 1·7 times full-load torque with twice full-load current. With the 6-pole connection it gives 2·4 times full-load torque with 3·6 times full-load current. With a 4-pole connection it gives 3 times full-load torque with 8·6 times full-load current. Thus for many purposes the squirrel-cage motor is all that is required, and can be used where a squirrel-cage motor of the single-speed type would be quite useless. For certain purposes, particularly in large sizes, resistance starting is of considerable importance, for instance when the motor is required to start with from 2 to $2\frac{1}{2}$ times full-load torque. For this purpose a slip-ring type

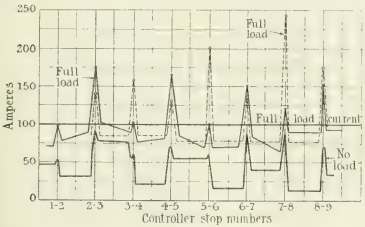


FIG. E.

of motor can be built in which the rotor winding is arranged so that the current flows through the slip-rings when the machine is connected for its top speed only, while on all other speeds the slip-rings are at the same potential and consequently no current flows through them, the secondary currents circulating entirely within the rotor. The second point referred to above relates to the smoothness of speed-change from one step to the next in such a multi-speed motor. This speed-change is effected by arranging the controller to change the speed in two steps. The first step of the controller changes from any one speed to the next. At the same time it inserts resistance in the line. The second step cuts out the resistance without making any further change in connections. By the use of this resistance a perfectly gradual rate of change from one speed to the next can be obtained. Fig. E is an interesting curve showing the conditions in a 5-speed motor both with and without (dotted curves) the gradual acceleration device.

Mr. Ll. B. Atkinson: It is, in my opinion, none too soon that the question of alternating-current commutator motors should be discussed at an Institution meeting, as no communication on the subject has appeared in the *Journal* since Mr. Creedy in 1904 read a paper before the Students' Section. In 1898 I read a paper before the Institution of Civil Engineers on "The Theory, Design and Working of Alternate-current Motors," in which the principles and action of commutator motors were set out and analysed, and their advantages for variable speed made clear, and it is of interest to consider the reasons why this class of motor has not received attention. One of the reasons why the advance of this type of motor has been so slow is that as long ago as 1898 we were still having very considerable trouble with the commutator of a direct-current machine, and everybody was looking forward to the polyphase motor with no commutator or perhaps even a squirrel-cage rotor without collecting rings, and consequently I was quite unable to interest any constructors to carry out experimental work on a machine which embodied a commutator. The result was that I carried out a good deal of experimental work myself. Mr. Edward Cowan and I put a good deal of money into that experimental work, but we stopped it after two or three years for reasons partly financial and partly owing to circumstances that had nothing to do with the motor. Within 12 months of my dropping the patents owing to the impossibility of getting any interest taken, the Westinghouse Company of America approached me and asked me if the patents could be taken up again. This shows the disadvantage of choosing an unlucky psychological moment. The next thing which in my opinion stopped the progress of this particular type of motor was this fact that all the patents were dropped, as no one then had any monopoly interest in developing the motors. To-day the position has not changed very much, notwithstanding that in our long-distance railway electrifications we can use, by adopting these motors, a variable pressure of supply to the motors to give variable speeds. Notwithstanding that enormous advantage, there is only one English engineer who has had the courage to say: "This is a method that will and must be adopted for long-distance railway electrification." That engineer is Sir Philip Dawson.* In the future, main-line electrification, with the long-distance transmissions that must exist, will have to be worked with high-pressure alternating current and, I believe, using the types of motor that we have been discussing to-night. The next point that arises is trouble which all the large generating stations are experiencing in the bad power factor which is given by the smaller type of induction motors—by the larger type also, but by the smaller sizes in particular. It has reached a stage where we are faced with capital outlay on the generating stations and cables, capable of generating and transmitting something like 50 to 70 per cent in excess of the real power load which they carry. In other words, we are dealing with a large kilovolt-ampere output and a smaller kilowatt output. That difficulty can be overcome by the use of this type of motor. This was pointed out for the first time, I believe, in my British patent

* I might also refer to the paper by Messrs. J. DALZIEL and J. SAYERS on "The Single-phase Electrification of the Heysham, Morecambe and Lancaster Branch of the Midland Railway." *Minutes of Proceedings of The Institution of Civil Engineers*, 1909–10, vol. 179, p. 47.

No. 835 of 1898, in which I described the use of a compensating field (magnetic) for the purpose of controlling the phase of the currents so as to increase the power factor. The author has used the phrase "compensated motors." One of those compensations is a balancing of the flux which passes through the brushes or through the armature so as to reduce the reactance. The other form of compensation is the compensation of the phase position. I think a better word for the first case in order to avoid confusion would be "neutralization." The two words I have employed—"neutralization" and "compensation"—are in use in America for the two separate functions, and I think it would be well if they were adopted in this country. There are three small books which I would recommend to those interested in the subject, viz. "The Classification of Alternating-Current Motors," and two books on "Phase Compensation," one for single-phase and one for three-phase current, all by V. A. Fynn, consulting engineer to the Wagner Company, St. Louis, U.S.A., which give a mine of information.

Sir Philip Dawson: The idea has always prevailed that the single-phase motor was a foreign importation and a foreign invention. I am very glad that this misunderstanding has been entirely removed, and that henceforward nobody can say that the single-phase motor was imported into this country. It is like many other British inventions: it was invented in Great Britain and then, for some reason which we need not examine too closely, was developed by foreigners. I have here a diagram which shows what actually takes place in the acceleration of the electric trains on the Crystal Palace line. It shows that for a very considerable period of acceleration an even rate of acceleration is obtained. That is an advantage to the passenger, but it is an even greater advantage from the point of view of the maintenance of the rolling stock. I should like to call the attention of members to that particular point of view, because, if they compare that curve with curves giving an equal rate of acceleration within 25 seconds from the start, they will find that in a direct-current motor the rate of acceleration at the start is very much greater, although in 25 seconds the same speed is obtained as that shown on the curve. From the experience which we have had, I think it can be said that for heavy traction work, wherever single-phase is adopted, the neutralized series motor will find general application. When the Brighton Railway first installed their single-phase traction system they utilized a type of motor which was practically in its infancy, and which therefore, as regards cost of installation, cost of operation and cost of maintenance, in order to be comparable with direct-current motors, ought to be compared with motors built 25 or 30 years ago. I should like as an example to illustrate the difference between the two types of motors. On the Brighton Railway the brushes have to be replaced after a life of between 6 000 and 11 000 miles, whereas the brushes on a motor the characteristics of which are shown on the diagram have to be renewed only after 40 000 to 50 000 miles. Although the commutation is not as good in the early type of motor, which is still in use on the Brighton Railway and which has been running since 1909, our experience shows that the average life of a commutator is 10 years or more, equivalent to a life of over 500 000 miles. As regards the capital cost, the latest tenders show that the cost of an alternating-current equipment, such as is shown in the diagram, is only between 15 and 20 per cent greater than the cost of a direct-current 750-volt equipment. I am led to believe, therefore, that alternating current will probably be largely used in the future for long-distance work where heavy trains are concerned. The Swiss have definitely decided to electrify the whole of their railways on the single-phase system. They have already electrified the St. Gothard line. The Swedes have electrified a section of their lines on this system and have decided to continue it, and I am informed that the Norwegian Government have come to the same conclusion. Germany still abides by the decision which she arrived at before the war, and Austria has joined her. Perhaps it is not realized that the single-phase system is by far the most extensive in use to-day in connection with electric locomotives. In the United States there are some 386 miles of lines working on a low-tension direct-current system on which 123 electric locomotives are operating. There are nearly 1 100 miles of lines working on a high-tension direct-current system, over which 90 electric locomotives are operating, and there are 634 miles of lines working on an alternating-current system, over which 224 locomotives are operating. Therefore, the number of alternating-current locomotives is at least equivalent to that of the direct-current locomotives. In Europe we find that the mileage electrified is 1 664 on the alternating-current system, with 275 electric locomotives operating. Italy has 215 miles, with 150 three-phase locomotives in operation. I think that shows that very considerable progress has been made in the application of single-phase work for main-line railway electrification. The question of which system is to be adopted is purely one of money. That system which, taking the capital cost and the cost of operation and maintenance, is the most favourable for any particular set of conditions will undoubtedly be the system which will have to be adopted in any given case. As a member of the Railway Electrification Committee of the Ministry of Transport, I signed that Committee's unanimous Report, and I entirely agree with it for the reason that it purposely left the door open so that, where any main-line electrification was to be considered on which a pressure of 1 500 volts was not financially satisfactory, the Company concerned had the right to go to the Minister of Transport and put the case before him, in order that it should be decided whether the system suggested for solving their problem should or should not be adopted. The evidence which I was able to bring before that Committee as regards the electrification of the main line to Brighton satisfied them that it would be proper to allow the single-phase system to be continued on the suburban system and extended to Brighton.

Professor E. Wilson: I should like to show a

slide which has been prepared from British Patent 18 525 of 1888, giving a side elevation (Fig. F), a section through the stator and rotor (Fig. G), and an end view (Fig. H) of the original commutator motor which is exhibited this evening. It resembles an ordinary direct-current motor in that the rotor, which has a diameter of $5\frac{1}{4}$ inches, is provided with a commutator connected to a drum winding. Two commutators, C_1, C_2, are shown as illustrating for two-phase working the use of one complete winding for each phase, but the patent provides for a single commutator to serve for the two phases. The stator has an axial length of 6 inches, and an overall diameter of 14 inches. It consists of laminated stampings (see Fig. G) with 4 polar projections, D, and windings, B, each of which consists of two separate coils: thus the two phases could be separated if desired, or one circuit could be employed for both. One of the coils on each projection could be used as a transformer secondary if desired. I should like to call attention to the brush sectors S_1, S_2 (see Fig. H), which enabled the brushes

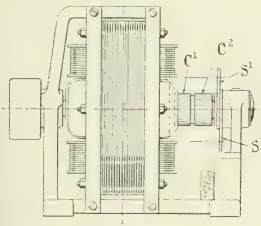


Fig. F.

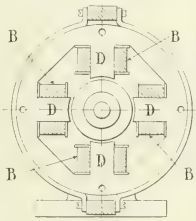


Fig. G.

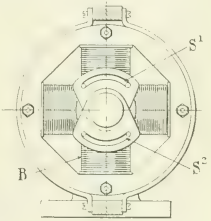


Fig. H.

to be moved round the commutator. For two-phase working the 4 brushes were spaced at equal distances apart on the commutator, and were all capable of being shifted, still maintaining their relative intervals. The stator and rotor were connected in series for variable-speed operation due to brush shift. The patent does not limit the motor to two-phase working, and it anticipates the use of more phases. The machine was arranged for single-phase working, and the circular slots in the sectors S_1, S_2 allowed one pair of brushes to be moved relatively to the other, as in the case of a repulsion motor.

Lieut.-Colonel B. C. Battye (*communicated*): Can the author give some information as to the facilities for regeneration when using the series neutralized single-phase motor? I have recently returned from a trip in the cab of an electric locomotive while travelling down the eastern slopes of the Rocky Mountains, and I was impressed with the great advantages derived from regenerative braking. I am convinced that for mountain sections this may now be looked upon as an essential feature, which can be satisfactorily effected by high-tension direct current, although I am inclined to be prejudiced in favour of single-phase work if only we can overcome the difficulty of special frequency. There was no mention in the paper or discussion of the limiting frequency at which the voltage induced in the short-circuit armature coils can be satisfactorily neutralized at other than synchronous speeds. Some information on this point would be of great value. We are about to go ahead with the electrification of one of the first mountain railways in northern India, and at present it is proposed to adopt the high-tension direct-current system, so that the whole question of railway electrification is one of vital importance to Indian engineers at the present moment.

Mr. F. J. Teago also took part in the discussion. The substance of his remarks is contained in a paper on "Test-Results obtained from a Three-phase Shunt Commutator Motor" which will be found on page 328.

[**Dr. S. P. Smith's** reply to this discussion will be found on page 326.]

North-Eastern Centre, at Newcastle, 28 November, 1921.

Mr. F. H. Downie: I have had some experience with single-phase commutator motors of both series and shunt characteristics. The shunt commutator motor had rotor excitation and was built by the Allgemeine Elektricitäts Gesellschaft. Its power factor was nearly unity at all loads. It started as a repulsion motor. The changing-over from repulsion to shunt motor was rather troublesome, since if it was not made at exactly synchronous speed the motor took a large current and sparked badly at the commutator. Since the output of polyphase commutator motors is limited by the transformer voltage induced in the coils short-circuited by the brushes at standstill, I take it that the figure of 15 to 20 h.p. per pole is for motors the starting torque of which is equal to full-load torque. If the starting torque can be reduced

as in the case of fans, these motors can be built for larger outputs at 50 periods per second. The Americans claim to be able to build motors for fan work, having a maximum output of 30 h.p. per pole at 60 periods per second and 70 h.p. per pole at 25 periods per second. Since the transformer voltage is proportional to the frequency, the motor can be built for larger outputs by reducing the frequency. This can be done by using the slip frequency of an induction motor, so that in the case of the combination shown in Fig. 5 (B) a large motor (1 500 to 2 000 h.p.) can be built, the speed of which can be varied from 20 per cent below to 20 per cent above synchronous speed. I should like to know whether the author has had any experience with the Kramer rotary-converter system [Fig. 5 (A)]. I have heard that there is difficulty in keeping the rotary converter in synchronism when the slip frequency falls to about 2 periods per second. Can this trouble be overcome?

Mr. A. T. Robertson: The first paragraph under Section (2) of the introductory notes is by no means clear. I would suggest that a more simple way of explaining the general case would be to say: "The action of the commutator is such that the frequency of the electromotive force at the brushes is that with which the flux cuts the brushes, and as both the stator windings and brushes are stationary the frequency with which the flux cuts both of them is the same independently of the sense or speed of rotation of the rotor; this renders it possible to connect the stator and rotor windings in series or in parallel." Referring to Section (4) (i), it is stated under (C): "All motors of the repulsion type are ill-suited for wide speed-ranges." Then under (E): "The types in (C), (D) and (E) are admirably adapted for small and medium outputs for industrial purposes, with speed-ranges varying roughly from standstill to about 30 per cent above synchronism." Standstill to any speed is infinite speed variation, so that the bare statements as they appear are contradictory. The statement in Section (5) (i) that the direction of rotation depends on which side of the short-circuit axis the brushes lie, and is independent of the sense of the rotary field, is misleading because one would naturally conclude that the reversal of such a machine would be simply a matter of movement of the brushes from one side of the short-circuit axis to the other. This, however, is not the case, as it is necessary in practice to reverse the sense of the rotary field in order to obtain good commutation and low iron loss. In general, it is necessary to arrange that the relative rotation of flux and rotor is such that the frequency of the flux in the secondary iron (either stator or rotor) is zero at synchronism, so that it is always less than in the primary. In this connection also, the word "stator" at the end of Section (5) (i) should read "primary," so that the sentence is applicable to motors of the form shown in Fig. 4 (C). The author assumes a figure of 15 to 20 h.p. per pole to be the desirable limit for the output of three-phase commutator motors. I notice, however, in the current issue of the *General Electric Review* (1921, vol. 24, p. 923) that 30 h.p. per pole at 60 periods and up to 70 h.p. per pole at 25 periods for motors of the series type shown in Fig. 3 (B), is suggested as being roughly the limiting output. Although single-phase repulsion motors have been discussed there has been no mention of three-phase repulsion motors. In 1914 Alexander Heyland (see *E.T.Z.*, 1914, vol. 35, p. 725; also abstract in *The Electrician*, 1914, vol. 74, p. 149) described a motor of this type, which was capable of phase compensation and speed variation, and it would be interesting to hear if any practical development of the type has been found possible. As there are no connections to the rotor no transformer is necessary to obtain a low-voltage commutator, so that if the practical difficulties are no worse than on other types, polyphase repulsion motors would appear to be the simplest for duties where series characteristics are required, and where wide speed-ranges are not essential. Innumerable patent rights have been granted in connection with motors of the types described, but comparatively few of the patents have been put to commercial use, so that manufacturers have little knowledge as to whether or not it is possible for them to make any particular type without infringing the rights of obscure patents. I think that this factor is to a large extent responsible for the reluctance of manufacturers to spend time and money on developing alternating-current commutator motors.

Mr. A. B. MacLean: Apart from the application of alternating-current commutator motors to traction, there is a wide field of industrial applications for such machines. With the growth of alternating-current networks and the increased use of alternating current there is bound to be a big demand for alternating-current motors with economical speed regulation, and it appears as if this demand could be largely met by alternating-current commutator motors, either single-phase or three-phase. If these machines can also be arranged to run with high power factors an additional advantage will be obtained, and probably in many cases the user will benefit financially on account of the improvement in power factor as well as the increased economy in the consumption of power. Equipments of the types illustrated in Figs. 5 (B), 5 (C) and 5 (D) have been largely used in the United States for rolling-mill drives in which the mill has to be run continuously in one direction but where a certain amount of speed variation is required to deal with the different classes of material which are being rolled at different times. By arranging the auxiliary equipment so that the mill motor can be run both above and below synchronism, the size of the auxiliaries is kept down to a minimum, and it is fairly obvious that for moderate speed-ranges such an equipment as that illustrated in Fig. 5 (B) will be very much cheaper than an equipment including a rotary transforming plant and a direct-current variable-speed motor. There is a modification of the equipment illustrated in Fig. 5 (B) which is of considerable interest and importance, especially in view of its application to rolling-mill drives. I have had experience of two equipments of this type, and the results obtained have been very satisfactory. The arrangement is similar to that shown in Fig. 5 (B), with the exception that the commutator motor is series wound. In this way it is arranged that the field strength of the commutator motor is proportional

to the rotor current of the main induction motor. The commutator voltage opposes the slip-ring voltage of the main induction motor and thus produces increased slip. The "slip power" is all restored to the main source of supply through the induction motor which forms part of the auxiliary set, with the exception of that proportion which is used up in the copper and other losses of the auxiliary equipment. In this way the natural slip of the main mill motor is considerably increased in the most economical manner possible. The load/speed characteristic is similar to that obtained by the use of a permanent slip resistance, without the serious losses of power which occur with the latter. It should also be noted that this auxiliary equipment can be used as a phase advancer by arranging the design of the commutator machine so that there is a phase difference between the commutator voltage and the slip-ring voltage of the main motor. The author has pointed out that there is room for further applications of equipments such as those illustrated in Fig. 5, and further, that an equipment of a similar nature might be developed to take the place of the Ward-Leonard sets used for electric winders and reversing rolling mills. It appears to me, however, that in such cases the auxiliary equipments would of necessity be of almost equal capacity to that of the main driving unit so that no advantage would be obtained, as the whole equipment would then be as costly as the Ward-Leonard set and would probably involve equally heavy power losses.

Mr. R. J. H. Beaty: There is one point on which I should like more information. In describing the series motor as used for single-phase traction, I understood the author to say that the transformer E.M.F. induced in the short-circuited coil of the armature is neutralized by using an interpole winding. Now, the effect of the interpoles will vary with the speed, and if the motor "stalled" there would be no counter E.M.F. at all, whereas the transformer E.M.F. is constant with a given flux and frequency. It would appear that one of the most important points in the design of a.c. commutator motors is to keep the transformer E.M.F. at the brushes below a certain value. In anything but the smallest sizes there would be only one turn per commutator bar in any case, so that for any given frequency a limiting value for the flux per pole is reached. Now, if the flux density be reduced, the motor will deserve the criticism which the author has so strongly and correctly urged against the variable-speed direct-current motor, i.e. that the material is not efficiently utilized. There is therefore a limiting value for the pole area, and the only way to get more power is to use a greater number of poles.

[**Dr. S. P. Smith's** reply to this discussion will be found on page 326.]

Liverpool Sub-Centre, at Liverpool, 12 December, 1921.

Mr. J. S. Peck: The development of a successful alternating-current commutator motor has long been the goal of the electrical designer, as it holds great possibilities in regard to speed and power-factor control. There is no great difficulty in manufacturing motors of this type for low horse-powers, but the difficulties increase very rapidly with the size, and it speaks well for the courage and engineering ability of certain manufacturers that they have been able to produce successful motors of fairly large size, but I doubt if any firm has made a financial success of this type of machine, especially in connection with those of larger outputs. A successful commercial motor must be able to work on a 50-period circuit, and to build a commutator motor for 50 periods is a much more difficult problem than building one for $16\frac{2}{3}$ or even for 25 periods. It should be noted that $16\frac{2}{3}$ is the frequency adopted on the Continent for single-phase railway motors. From time to time I have had opportunities of discussing the question of a.c. commutator motors with Continental and American engineers, and I have found that the more experience they have had with this class of machine, the more definite becomes their opinion as to the difficulties in design, manufacture and operation. One engineer, whose firm has been prominently associated with the development of the type of machine under discussion, made the following comment: "The d.c. motor has its particular troubles; the induction motor has troubles peculiar to itself; the a.c. commutator motor has all the troubles of the d.c. motor, all the troubles of the induction motor, and then a particular and peculiar series of ailments of its own." I think this statement fairly well expresses the opinion of most engineers who have been responsible for the design of this type of motor. I believe that the a.c. commutator motor has a certain very limited field as a phase advancer, or power-factor corrector on large induction motors. It may have a considerably larger field as a means of controlling the speed of large induction motors, but the complications involved in this system of speed control are such as to make most practical men hesitate to adopt it. I do not believe that there is a large field for this type of machine, as a simple variable-speed motor. Its advantage is that it may be coupled direct to the a.c. mains without converting plant being necessary, and in a large installation where the great bulk of the machines are constant-speed motors it will probably be cheaper to install a variable-speed a.c. motor than to put in converting plant. If many variable-speed motors were required in any particular installation, it would be safer, cheaper and more satisfactory to install converting plant than to put in a.c. commutator motors.

Mr. D. I. Dawbarn: One of the most interesting points in Fig. 4 (C) is the variation in the position and diameter of the circle diagram for the motor working against full-load torque with varying speed. The character of the circles is shown in Fig. J, the variation in the position being due to phase-changes in the resultant E.M.F. in the current found by the brushes and the stator windings, whilst the variation in diameter is due partly to the differing magnitude of the resultant

E.M.F. and partly to changes in the coefficients of self and mutual induction as the speed changes.

Mr. E. W. Young: An objection to the type of motor described in Fig. 4 (C) is that they are liable to hunt. Fig. K shows the speed-range within which

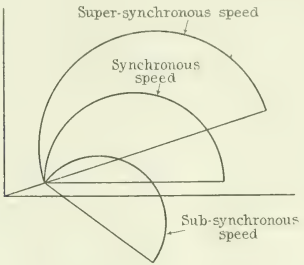


FIG. J.—Circle diagrams for motor on load.

hunting occurs in a 5–15 b.h.p. motor at no load and full load. The speed variation would probably not matter greatly for most purposes, but for some purposes a variation in speed of 1 per cent is too great. Although, for a given load, there is only one speed at which

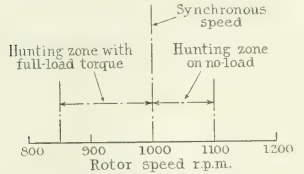


FIG. K.

NOTE.—Speed variation attains its maximum of 1 per cent approximately when mid-zone speed is reached.

hunting becomes a maximum, and though the zone in which hunting can be detected is narrow, it should be borne in mind that hunting is a characteristic of these machines.

Professor E. W. Marchant: There is one obvious point in connection with the author's statement as to the constant power given by a shunt-wound motor when working with a given current but with variable field. If the motor is running on constant-pressure mains and takes a given current, and if its efficiency is constant, the power which it will develop must be constant. As a rule, the efficiency with full-load current will not vary to any great extent, so that in practice the output will remain very nearly constant. The author appears to indicate that from the point of view of speed variation the alternating-current commutating motor is better than the direct-current motor. This, I think, is not an intrinsic property of the motor. The greater ease with which the speed can be controlled is due to the ease with which variable pressures can be obtained with alternating current. As the author says, the weight of a single-phase commutator motor must always be greater than that of a direct-current motor of the same rating, because the "specific utilization of the material" is always less effective than it is with direct-current machines, or, conversely, with a given size of motor the rating with direct current is much higher than it is with alternating current. The three-phase commutator motor should prove a very valuable machine for special cases. The motor to which Mr. Teago refers has a very much higher efficiency over a wide range of speeds than an induction motor, and, as the author has stated, the commutation is remarkably good. The motor is a much more expensive machine to construct than the induction motor, and can be used only in cases where a wide range of running speed is required.

Mr. C. Rettie: I am especially interested in the use of motors for electric ship propulsion and heavy railroad work. But as alternating-current commutator motors are out of the question for such large powers as are used for the electric propulsion of battleships in America, the size of motors of which varies from 7 000 to 22 000 h.p., and as the low-powered ships such as cargo boats, ferryboats and the like, will probably use direct current, the alternating-current commutator motor can be ruled out, as far as ship propulsion is concerned. However, there is a great future for this motor on heavy railroad work, and although the Government have standardized the high-tension direct-current system on our main-line railways, it is probable that before any great scheme is embarked upon the question of system may be changed, especially in the light of recent developments which have taken place in Switzerland with the use of the single-phase system. Mr. Hobart in his book * on motors mentions the fact that the Swiss State Railways after several years of operation of the single-phase system have found that it costs more than the steam-hauled trains and are replacing it by steam. Owing to the high price of coal, however, they soon went back to electricity; † it was seriously considered to use first electric heaters to raise steam on the existing locomotives until the electric locomotives were available. As far as railway work is concerned only the series neutralized type of commutator motor need be considered. The three-phase system is not likely to become popular for, according to reports from the Continent, although the three-phase system is in general use on the Italian Railways, the fact that a double trolley line has to be used will militate against the adoption of the system in any other country. On page 308 the author states that, with a single machine, voltage control is impracticable with direct current. I take this to mean when the current is taken from a fixed source of supply. It would not apply in the case of direct-current motors used for the electric propulsion of ships, as the voltage of the generators could be varied to suit the speed. Mr. W. E. Thau

* "Electric Motors; their Theory and Construction."

† See *Electrical World*, 1917, vol. 70, p. 1059; digest of an article in *Teknisk Tidsskrift*, September, 1917.

brings that point out in his recent paper before the combined meeting of Naval Architects, Marine Engineers, and the American Institute of Electrical Engineers in New York. In conclusion, I should like to refer to the author's statement at the commencement of the paper with reference to the disadvantages of the induction type of motor, either of the synchronous type or with the use of the phase advancer, as being far inferior to any alternating-current commutator motor. I disagree with the author on that point because for large powers the types referred to still hold the field, as commutator motors could not be used in their place except as regards the wound secondary motors where a small commutator motor is used for the phase advancer, or, as proposed by Mr. W. E. Thau in his paper already referred to, to try to raise the power factor of the induction type of motor with slip-rings, a method used in ship propulsion.

Mr. W. Holttum: The author stated early in the paper that in order to improve the power factor of alternating-current motors it is always necessary to install a commutator somewhere. I should like to ask him whether he had any special reason for omitting static condensers, seeing that these are now very largely used for power factor improvement. The paper is interesting as describing an article which has been made a commercial success in spite of very serious inherent disadvantages, and the author made it very clear that that success is a triumph of engineering skill and perseverance and, furthermore, that that triumph does not belong to British designers and engineers. It is difficult to say whether we have been wise in avoiding the risk of burning our fingers over what seemed a doubtful proposition, but the result is certainly one to be taken to heart and pondered over.

Mr. T. D. Clothier: My remarks refer more to the series of slides shown by Mr. Teago than to the paper. According to these slides the particular commutator motor examined had a working speed-range of from 500 to 1 500 r.p.m., with an efficiency of approximately 80 per cent over that range, the power factor appearing to be 0·4 at 500 r.p.m., rising to 0·98 at 1 500 r.p.m. It seems to me that under these conditions the consumer is not likely to benefit materially by using this type of motor if the supply is obtained on the kilovolt-ampere basis. Possibly, as the particular motor in question is small, these characteristics may not apply to larger models of the same type. I should like the author to say, therefore, how far these results can be accepted as true characteristics of this type of motor.

Mr. E. W. Ashby: On page 308 the author suggests phase advancement. This is a very desirable application and, with increasing demand and loading of cables, supply companies are insisting on new plant being of high power factor, and, because of the methods of charging, consumers also are becoming interested in this matter. It is exceedingly difficult to obtain small motors with a high power factor, and an installation of small machines will probably work at an overall power factor of about 0·7 lagging. In such cases it is rarely practicable to put in a synchronous motor, as the minimum size is about 150 kVA, but a few commutator motors with leading power factor might well be installed. I believe the leading power factor of a single-phase motor decreases with the load, so that the wattless component would still be in evidence on light loads. A machine having such characteristics has been marketed by an American firm for some 10 years. A variable-speed alternating-current motor with the same characteristics and ease of control as the direct-current interpole machine, produced at a reasonable figure, should have a large field of use. Commutation seems to be the chief trouble with three-phase motors, restricting the voltage they can be designed for, or necessitating transformers. The author mentions the fan drive as a particular instance of the use of an induction motor with resistances in the secondary circuit. This case is met by a special form of the Hunt cascade motor having a second speed equal to two-thirds of the normal speed, the torque being proportional to the cube of the speed in accordance with fan requirements.

Mr. J. W. A. Abernethy: In order to secure sparkless commutation in the three-phase motors described, is it necessary that the number of coils and commutator segments should be a multiple of 3?

Mr. F. J. Teago also took part in the discussion. The substance of his remarks is contained in a paper on "Test-Results obtained from a Three-phase Shunt Commutator Motor," which will be found on page 328.

[**Dr. S. P. Smith's** reply to this discussion will be found on page 326.]

North Midland Centre, at Leeds, 17 January, 1922.

Mr. W. B. Woodhouse: I have had some experience with this type of motor in the past—first of all with the series-characteristic single-phase motor in which the speed was regulated by shifting the brushes, and which behaved perfectly. The object for which that motor was used was rather interesting. Worsted spinning is carried on in this district very largely on cap frames in which the tension of the yarn depends upon the diameter of the particular turn that is being wound on the bobbin. With a constant speed of frame the tension of the yarn is constantly varying, and as a result the bobbin is not packed tightly. If the speed of the spindles is varied in relation to the diameter of the bobbins the tension of the yarn can be kept constant, and as a result the yarn is packed tighter, there is a bigger weight on the bobbin and a bigger output from the frame. That was all definitely confirmed by experiment. The disadvantage of the series-characteristic motor was that the average speed depended to some extent on the temperature of the spinning room and was very sensitive to changes of voltage. Undoubtedly for such a purpose there is a big field for a moderate-power variable-speed a.c. motor. The largest motor that would be required would probably be 20 h.p. I have had experience of larger

motors for fan driving; these were three-phase commutator motors like the Siemens and Scherbius motors that the author showed on the slides, and which for such a purpose were quite satisfactory up to sizes of 200 to 300 h.p. The large first cost was their only disadvantage. I have also had experience of other types of variable-speed a.c. motors which have not been satisfactory, and I am glad to hear that there are now several dependable types. One of the problems to be dealt with in a.c. supply is that of the electric winder for collieries. To-day the induction motor is being used for that work. Motors of 800 to 1 200 h.p. are now at work in this country winding coal, and are doing it quite satisfactorily, but the regulation is by resistance control in the rotor circuit and is not particularly efficient. If the energy consumption in those machines could be cut down by 10 or 20 per cent, the use of electricity would be helped forward.

Mr. R. C. Atkinson: When the question of variable-speed a.c. motors first came to my attention it seemed to me a rather uninteresting subject, but, perhaps rather superficially, I dismissed it from my attention as a development which had not reached any practical stage. Some little time ago I had, however, to take very definite notice of a commutator motor, and since then my opinion of the subject has changed very much. The machine was a single-speed single-phase commutator motor with shunt characteristics, and I was impressed by the way it started and operated under somewhat severe conditions.

Mr. F. S. Adkins: On page 312 the author says with regard to type (E), "No flux embraces the short-circuited coils when the brushes are in the neutral position." That is contrary to my experience, unless I confuse what he means by this position. In a repulsion motor, when the brushes are in the neutral position the machine sparks the worst. I have had some experience with single-phase commutator motors of the repulsion induction type, and I have found difficulty in building small repulsion motors with more than 6 poles, owing to the power factor, starting torque, and overload capacity being so very poor. With 8 poles the starting torque and power factor both became low. For instance, in a standard frame, 18 h.p. at 1 500 r.p.m. and 50 periods might be obtained, but at 750 r.p.m. the output will be about a third from the same frame. I should like the author to explain this. Is it possible to build small single-phase motors for 50 periods, to start as repulsion motors and change to shunt motors on reaching synchronous speed, without any centrifugal device or moving parts, so that they will still be capable of speed variation by voltage control in such a manner that the h.p. output is proportional to the speed?

Mr. W. E. Burnand: I think that the use of the small interpole for neutralizing the E.M.F. in the coils short-circuited by the brushes is as great an invention as the series neutralized winding. It is really that, combined with the neutralized winding, which has made the machine practicable in large sizes. It seems rather an open question as to which should be called the field and which the armature in these machines. At synchronism there is direct current in the commutated circuit of the machines (referred to in the paper as the armature) and alternating current in the part called the field. Thus, so far as the electrical action is concerned, the armature of the a.c. motor corresponds to the field of the d.c. machine, and the well-known fact that in a.c. machines a strong armature and a weak field make the best working combination, really corresponds to the equally well-known fact that in d.c. machines a strong field and weak armature are to be preferred to the reverse arrangement. Among the machines I have constructed is a sort of inverted machine made up originally for the purpose of getting a large torque at very low speeds without large variations of torque with small movement of the rotor portion. This is driving a taping machine in my works and gives unlimited variation in speed. The rotor is practically an armature turned inside out with stationary commutator attached. The field has salient poles and the brushes revolve with this and bear on the inside surface of the commutator; thus every segment can be observed whilst the machine is working. For studying commutation this would make an almost ideal arrangement, it being quite easy to join resistances up in some leads or to bridge a couple of segments with a condenser. It is possible that this stationary commutator arrangement may have some practical applications in large sizes where commutation conditions are difficult, owing to the facility with which the electrical constants of individual coils can be adjusted. Another type of machine not mentioned by the author is the machine with series characteristics and controlled by a governor. I took out a patent for such a machine some 15 or 20 years ago. The type of governor adopted was an eddy-current brake attached to the motor shaft, with adjustable magnets acting against a spring. This was geared to the brush rocker and could be set to keep the speed substantially constant at any desired value, exactly as the speed of a steam engine is kept constant by a governor, and it could be varied by suitable adjustments, so that whilst the motor had a series characteristic it was so controlled as to act as though it had a shunt characteristic. Since all power-factor correction in these machines is done in the armature or commutated part of the machine, it follows that the back E.M.F. in this part must lag in phase behind the line E.M.F. if it is to permit the current to lead with respect to the line E.M.F. It follows from this that all power-factor-correction devices dependent upon this back E.M.F. are really devices for making the field flux—which, in conjunction with the movement of the armature conductors, causes the back E.M.F.—to lag more than 90 degrees behind the impressed line E.M.F. A resistance or capacity in parallel with the field coils of a series machine permits this field to lag behind what it would be without this non-inductive shunt, with a resulting gain in power factor much above what would be obtained by this resistance or capacity directly in circuit, at any rate whilst the armature is running at reasonable speed.

Mr. F. Creedy also took part in the discussion. The substance of his remarks will be found on page 314 in connection with the discussion at the Institution.

[**Dr. S. P. Smith's** reply to this discussion will be found on page 326.]

South Midland Centre, at Birmingham, 1 February, 1922.

Professor W. Cramp: I cannot agree with the author that a direct-current motor with field control has a constant output over the whole range of its speed. I have always found that at the higher speeds the ventilation of the machine increases so that, when combined with the smaller field loss, the armature current and power may be increased considerably for a given temperature-rise. I am rather surprised at the author's very definite conclusion regarding the ultimate displacement of all forms of series a.c. motors by the neutralized series conduction motor. Commutation evidently has proved to be of more importance than power factor, so that we shall again be faced with the demand for a wattless current generator in railway generating stations. For work needing a shunt characteristic the most satisfactory machine that I have yet found is that described under (C), page 313, and I think that this machine should be developed in this country. The author refers several times to the unwillingness of supply authorities to make any concession to their consumers for improved power factor. With this complaint I can heartily sympathize. More than once I have offered on behalf of a consumer to put in a phase advancer, but I have met with no support whatever from the supply authority. The lack of development of the a.c. commutator motor in this

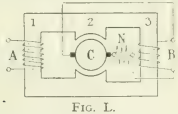


Fig. L.

country is in no sense due to lack of inventive genius or of patience and persistence. The author pays a just tribute to the astonishing early work of Atkinson. Other workers in the field have been Wilson, Hunt, Fynn and Creedy. All alike, with the exception perhaps of Hunt, have met with a chilly reception from manufacturers, of which I myself can speak with some feeling since the same reception greeted the motors that I developed in 1900 and 1908. Yet if we take this range of names we find that it accounts for practically every known form of a.c. commutator motor. Once again the history of the aniline dyes is repeated. Nor will development be stimulated by recent events. The decision of the Railway Commissioners in favour of direct current for main lines, in the face of Continental experience, is a blow—it may be a mortal blow—to the manufacture of a.c. series motors in this country; and its effect will be reflected for many years in the orders that can be secured here for machines required abroad. I have never been able to understand why the single-phase machine which I put forward 14 years ago has met with no support. I have brought the original here to exhibit to-night since even now it may be of interest to some manufacturers. Its principle is clear from Fig. L. Its characteristic is that of a series motor with all the advantages of which we have heard so much to-night. In addition there are the following manufacturing advantages: The coil A, which alone is connected to the mains, can be wound for any voltage, B and C remaining standardized and so proportioned as to give the best conditions for commutation. Since the ampere-turns acting across the air-gap are due to the primary and secondary coils in opposition, the air-gap can be made long and the pole-arc short. The power factor, commutation conditions and efficiency of the motor are all good and, in addition, control can be arranged from tappings on the secondary B. It should be ideal for fans and other machines made in quantities for stock.

Mr. R. Orsettich: With reference to the voltage control of direct-current motors mentioned at the beginning of the paper, I should like to point out that this method is used very considerably in the regulation of large motors such as rolling-mill motors, also for the control of printing machines, and for paper-making machines. In all cases this entails the use of an auxiliary generator or a booster to alter the supply voltage across the armature. With regard to the general application of commutator motors, there appears to be one point which has not been emphasized in the paper, and this refers to the question of frequency. There is no doubt that one of the main handicaps to the application of these motors is the fact that they work well only with frequencies of 25 periods and under, and that the largest number of applications made and referred to in the paper have been for motors working with a frequency of $16\frac{2}{3}$ periods. A frequency of 25 periods appears to be the absolute limit for traction work, and in fact a number of experts dispute even this and insist on a lower frequency being used. The author mentions that a number of firms who were manufacturing different types of motors on the Continent are now making series-wound motors with commutating poles, and I should like to explain that this was due to the situation as regards patents. There were three or four organizations competing with one another, and each one had taken out patents covering its particular type. They continued to push this type as long as the patents of the competing firms were in existence, and only when these patents fell through were they in a position to adopt the motor which had proved best. The reason for the very scanty attention paid to these motors in this country is mainly the fact that on the Continent the manufacturing companies own or control a number of supply companies, and thereby can influence the adoption of the particular type of motor. In this country, where the supply companies are independent of the manufacturers, the introduction of the motors is dependent upon the supply companies encouraging the use of any special type, and, as these special types are usually more expensive and more difficult to run, their development was retarded. Motors of the various types described have been at different times made by the company with which I am connected, and a number of them were installed,

but owing to the fact that there was no large or universal demand for them it has been found impossible to standardize them up to the present. Owing to the latest developments of power distribution in large towns, I believe that there will be a considerable field for small single-phase motors up to, say, about 10 or 15 h.p. where the supply authority will not bring into a building more than one phase of the three-phase distribution. There is therefore a possibility that a large number of small single-phase motors may be required in the near future. With regard to three-phase commutator motors, there also will be a moderate demand for such motors up to, say, 25 h.p. for installation in factories where an economical speed regulation is required. Unless such motors are available the only other solution of the problem would be to install motor-generators and d.c. motors. This, of course, makes the combination extremely expensive and not nearly so satisfactory from an operating point of view. In conclusion I should like to suggest that to the list of names given in the paper of people who have devoted a good deal of thought and ingenuity to the development of single-phase and polyphase commutator motors, should be added the name of Mr. V. A. Fynn, who for many years has studied these problems, and who has contributed a large number of papers to the Institution on the subject.

Dr. S. P Smith's Reply to the Discussions at London, Newcastle, Liverpool, Leeds and Birmingham.

London.—It is a matter for no small satisfaction that we should be honoured at the Institution this evening by the presence of our immediate Past President, Mr. Atkinson, who has probably done more than any other inventor in connection with single-phase commutator motors; of Prof. E. Wilson, the inventor of the polyphase commutator motor; of Mr. Creedy who, in addition to his inventions, has done so much to develop commercial alternating-current motors; and of Sir Philip Dawson, the pioneer of single-phase traction in this country. Further, the fact that this lecture is also being delivered at six Territorial Centres and Sub-Centres shows that, in Mr. Atkinson's words, it is none too soon that alternating-current commutator motors should be discussed. Doubtless the widespread adoption of alternating current is compelling engineers to study this problem.

Great credit is due to Mr. Creedy for the way in which he not only has developed satisfactory single-phase commutator motors, but has in face of great indifference and discouragement shown how such machines can be built to compete with the more standard types of motor. The curves in Fig. A will surprise most manufacturers. It is interesting to note that this success is achieved by building constant-speed motors to run at synchronous speed. Though Mr. Creedy does not share my view in regard to the great difficulties which the designer of alternating-current commutator motors has to face, he shows a decided preference for multi-speed induction motors on polyphase circuits. In this respect, however, in addition to not giving gradual speed-change, he sacrifices high power factor.

Like many other inventors, Mr. Atkinson has undoubtedly felt that he was long before his time. He has given one of the main reasons why these machines remained undeveloped. Other important reasons are: the small demand made standardization difficult, which resulted in the machines being too costly; the technical staffs of the firms were often unable or unwilling to design these motors, while inventors seldom had the advantage of practical design experience to go upon; direct current was extending for a number of years more rapidly than alternating current; and the keen competition in the electrical market, both between home and foreign firms and between native and imported designers, did not encourage development in difficult and unpromising fields. Mr. Atkinson's suggestion in regard to the use of the words "compensation" and "neutralization" is a good one. It would be better if the former were used solely for "phase compensation"; and the word "neutralization" for the counter-balancing of the armature flux, etc. The suggestion has been adopted in the revision of the lecture notes but I fear that the general acceptance of the innovation will take some time.

I am glad to hear from Sir Philip Dawson that neutralized series motors will be used in connection with the new rolling stock on the Brighton line. This is doubtless the type that will eventually supersede all other single-phase types. Instead of offering adverse criticism, British firms in their own interests ought to encourage the Brighton Railway to proceed with single-phase electrification. Great Britain is essentially a manufacturing country, and exists largely by exporting manufactured goods. In electric traction however, our firms have been very backward. Of the electrified lines in this country, very little of the equipment has been manufactured and still less has been designed here. The right policy for British firms is to design and manufacture the equipment for their own railways, and also to design and manufacture equipment for colonial and foreign railways. Thus it is desirable to experiment with both direct- and alternating-current electrification not only to determine which is the better for our own railways, but also to enable us to tender for any outside work that is offered. From every point of view, therefore, it is unwise for us to be one-sided in this matter.

It was very kind of Prof. Wilson to exhibit his original motor here this evening. It is interesting to note that the polyphase motor was invented by a man in the English firm of Siemens and developed by a man in the German firm of Siemens. The method of control by brush-shifting was clearly foreseen by Prof. Wilson. The difficulty of this inventor was not only in building the motor, but in obtaining a polyphase current to drive it.

Satisfactory regenerative braking with single-phase traction has been developed, and Col. Battye will find the systems of the Oerlikon Co., and of Messrs. Brown, Boveri in use on the Swiss railways. It does not seem to be feasible to exceed 25 periods for single-phase traction, and doubtless $16\frac{2}{3}$ periods is a better frequency. The latter advantage largely accounts for the rapid, successful strides in single-phase traction in Europe.

Newcastle.—There are numerous devices for starting shunt motors as repulsion motors, and Mr. Downie will find that in some of them no change-over switch whatsoever is required [cf. Fig. 2 (c)]. The output per pole depends largely upon starting conditions; thus a fan motor starting light may well be designed for 30 h.p. per pole, while 20 h.p. per pole may be high enough for starting under full-load conditions. I do not know of any means of making the rotary converter stable below 2 periods per second. Where possible it would be well to cut the auxiliary machines out of circuit when the slip is so small.

I cannot see any advantage in Mr. Robertson's definition, or how the flux "cuts the brushes." The statements about speed-ranges are not misleading. A motor with a speed-range from standstill to 30 per cent above synchronism has not a wide speed-range compared with the series motor, the speed-range of which may be from standstill to 5 or 10 times synchronous speed. Remarks similar to those of Mr. Robertson regarding section (5) (i) could be made about every type mentioned, but instead of introductory notes a text-book would be needed.

The points mentioned by Mr. Beaty are among those around which the design of alternating-current commutator motors pivot, but increasing the number of poles is advantageous, except for the increase in commutator losses. The contact resistance of the carbon brushes has to be relied upon very largely for suppressing circulating currents due to the transformer E.M.F. Even with interpoles, as in the neutralized series traction motor, compensation is correct at only a few speeds; at other speeds and at standstill brush or other resistance must keep the circulating currents within permissible limits.

Liverpool.—While agreeing with Mr. Peck's criticisms, I cannot accept his conclusions, because satisfactory, reliable motors of all types are now being built. Some firms will doubtless postpone the manufacture of these machines as long as possible, but history repeats itself here as elsewhere.

I am obliged to Messrs. Teago, Dawbarn, and Young for the interesting contributions they have made in connection with the three-phase shunt motor with movable brushes.

Prof. Marchant's remarks about the speed-control and output of d.c. as against a.c. motors appear neither to controvert nor, as far as I can see, to improve what I have said. He also goes too far in stating that the weight of a single-phase commutator motor must always be greater than that of a d.c. motor of the same rating. This remark entirely ignores the effect of the number of poles.

Mr. Rettie is right in saying that my remark assumes a fixed source of supply. Obviously the Ward-Leonard system provides voltage-control with the d.c. motor, just as a transformer gives it with the single-phase series motor. I did not state that the non-commutator types were inferior to the a.c. commutator motor; such a statement would be entirely wrong.

In reply to Mr. Holttum I would say that I had only machines in mind when I spoke of power-factor correction.

If Mr. Clothier refers to Mr. Teago's paper (see page 328) I think he will find that the power factor of his motor at 500 r.p.m. is approximately 0·6 and not 0·4, while with suitable adjustment unity power factor is possible over most of the speed-range.

In reply to Mr. Abernethy, I know no reason why the number of coils or segments must be a multiple of 3, unless in any given case a symmetrical lap-connected winding implies this condition.

Leeds.—Mr. Adkins is confusing what I said about the repulsion motor with fixed and movable brushes [Fig. 1 (E), the Deri motor] with the repulsion motor with movable brushes [Fig. 1 (D)]. What I said was correct. Without the design particulars I could not say why his motor gave such little output when designed for half speed. Of course, the commutator losses may become considerable at low speeds. In reply to his query, after changing over from repulsion to shunt connections, the speed could then be varied as indicated in Fig. 2.

Birmingham.—Prof. Cramp's remark about the d.c. motor with field control is more of a quibble than an argument. The general statement I made was correct; and all that he says about improved ventilation applies equally well to any other type of variable-speed motor. If ventilation, commutation, losses, etc., are considered, obviously a little more or less output will be obtained, but the point is quite irrelevant in connection with the argument. Prof. Cramp is obviously pessimistic about the power factor of single-phase series motors for traction, but under normal conditions the power factor is very high. I fully sympathize with Prof. Cramp as an inventor of single-phase commutator motors, and I am glad that he emphasizes my warning about the importance of a.c. traction to our manufacturers.

Mr. Orsettich's remarks about frequency relate to traction motors and not to the general application of commutator motors. All types of a.c. commutator motors are built for 50 periods. It is encouraging to learn that there is likely to be a useful demand for both single- and three-phase commutator motors for small outputs, and it is hoped that our firms will attempt to standardize at least a few commercial sizes. As mentioned in the lecture, this was not the proper occasion to refer to individuals and firms connected with the various types of motors, but it is at least satisfactory to know that as regards inventors of types this country stands supreme.

I am greatly indebted to the several speakers who have taken part in the discussions, and I can only hope that the great interest shown in this attempt to arouse activity in a.c. commutator motors will bear good fruit in the electrical industry of this country.

TEST-RESULTS OBTAINED FROM A THREE-PHASE SHUNT COMMUTATOR MOTOR.

By F. J. Teago, Member.

(*Paper first received* 16*th January, and in final form* 10*th March*, 1922.)

Summary.

The subject-matter of this paper consists of the results of tests on a three-phase shunt commutator motor manufactured by the Swedish General Electric Company.

There are three main divisions :—

(*a*) The operation of the motor, as normally supplied by the manufacturers, with symmetrical brush-gear setting.

(*b*) The operation of the motor with variable brush-gear setting.

(*c*) That portion of the theory, with the vector diagrams, necessary for understanding the operation of the motor.

The motor on which the tests referred to in this paper were made is described by the manufacturers, the Swedish General Electric Co., as :—

Type F.S. 7.	Horse-power 5–15.
R.P.M. 500–1 500.	Periodicity 50. Poles 6.
Primary volts 400.	Secondary volts 39·5.
Primary amperes 14–21.	Secondary amperes 86.

The tests were made in the Electrical Engineering Laboratories of the University of Liverpool.

The motor is rated at 5 b.h.p. continuously when operating at 500 r.p.m., and at 15 b.h.p. when running at 1 500 r.p.m.

The motor has the usual stator and rotor ; the stator, however, carries the secondary winding, and the rotor the primary winding, and herein lies one difference between this motor and an ordinary induction motor. Another, and fundamental, difference is that the rotor also carries an ordinary lap winding in the same slots as those which contain the primary winding. This lap winding is connected to a commutator in the usual manner associated with direct-current machinery, but in order that three-phase current may be taken from the commutator it is necessary to fit three brushes, spaced 120 degrees apart, for each pair of motor poles, and each brush must consist of two separate halves which can be moved relatively to one another. The function of this lap winding is to inject into the secondary windings an E.M.F. and cause the secondary windings to develop a counter E.M.F. of almost equal value. Obviously, the magnitude of the secondary counter E.M.F. is a function of the speed of the rotor which carries the primary winding. Hence, if the magnitude of the injected E.M.F. can be varied, the speed of the motor can be controlled.

The machine really operates as an induction motor with the primary winding carried on the rotating element, and has the special feature of being able to operate at speeds below and above synchronism. At sub-synchronous speeds the motor speed is such that the induced E.M.F. exceeds the injected E.M.F., and as the injected E.M.F. is reduced to zero the motor speed will approach synchronism because the induced E.M.F. is zero at synchronous speed. If, after passing through zero, the injected E.M.F. is reversed and increased, the motor speed will rise above synchronism because a super-synchronous speed causes the induced E.M.F. to increase and reverse ; but the motor speed will now be such that the induced E.M.F. is less than the injected E.M.F. because the circulating current does not reverse. If the circulating current were to reverse, then the direction of rotation would be changed.

This particular motor has six poles and a synchronous speed of 1 000 r.p.m. Since the commutator requires three brushes, 120 degrees apart, per pair of poles, there are altogether nine brushes. Each brush consists of two halves placed in separate boxes and mounted side by side in the axial direction of the commutator. Nine of the half brushes are carried on one rocker and are fixed so that each moves if the rocker moves. The other halves are carried on a second rocker in a similar manner. The brush movement which controls the motor speed consists in moving the rockers in opposite directions so that the two halves of any one brush have relative motion.

As will be seen later, the relative positions of the brush rockers control the distance between any pair of half brushes, and thereby control the magnitude of the E.M.F. injected into the secondary phase connected to these half brushes. The brush-rocker positions, therefore, control the speed of the motor.

The torque of the motor is provided by the interaction of the magnetic field due to the primary winding, and the current flowing between the lap and secondary windings, which is described as the circulating current.

The primary winding is star connected and is carried in the bottom portion of the rotor slots. It is fed from slip-rings mounted on the shaft, which is hollow, and contains the leads from the slip-rings to the primary winding. The top portion of the rotor slots contains the lap winding which is connected to the commutator. Fig. 1 shows a section through a rotor slot. With respect to this slot the following assumptions are made :

(*a*) That there is no appreciable leakage between the two separate windings.

(*b*) That the primary resistance-drop is in phase with the primary current, and

(*c*) That, since the leakage flux is due to the resultant ampere-turns in the slot, the primary leakage reactance-

drop is at right angles to the resultant lap-primary current.

The secondary winding is carried in the stator slots; the three phases are kept separate and the six ends are brought out and connected to the commutator

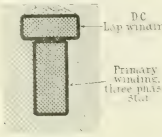


FIG. 1.—Section through rotor slot.

brushes.* Fig. 2 shows how either phase of a two-pole three-phase shunt commutator motor is arranged. In these notes the E.M.F., current, etc., due to the secondary winding are referred to as "induced," whilst those due to the lap winding are termed "injected."

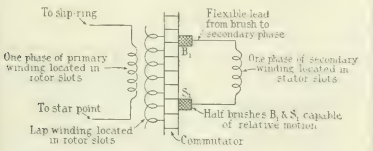

To slip-ring
Flexible lead from brush to secondary phase
One phase of primary winding located in rotor slots
One phase of secondary winding located in stator slots
To star point
Half brushes B1 & S1 capable of relative motion
Lap winding located in rotor slots
Commutator

FIG. 2.

Considering, for the sake of simplicity, a two-pole motor, the brush-gear parts are shown in their approximately correct positions corresponding to various speeds in Figs. 3, 4 and 5.

Fig. 3 shows the brush position corresponding to a no-load speed of about 500 r.p.m. The half brushes third to B_3 and S_3. In this position the E.M.F. generated by the lap winding, between either pair of the half brushes such as B_1 S_1, is that due to one-third of the conductors in the lap winding.

Fig. 4 shows the brush position corresponding to a no-load speed of about 965 r.p.m. In this position the E.M.F. between a pair of half brushes is zero.

Fig. 5 shows the brush position corresponding to a no-load speed of about 1 600 r.p.m. In this position the E.M.F. between a pair of half brushes is that due to one-half of the conductors in the lap winding.

The readings of a voltmeter placed between pairs of half brushes confirmed these statements, the reading for Fig. 3 being lower than that for Fig. 5. All three pairs gave similar sets of readings. These voltmeter readings were taken with the secondary windings disconnected from the brush-gear and with the armature at rest, the primary windings being supplied with three-phase current at the normal frequency and the brush-gear set to the required positions.

When the primary winding, located on the rotor, is fed from a three-phase supply a synchronous rotating field, distributed in the air-gap approximately according to a sine law, is produced. It is not possible to alter the rotational speed of this field with respect to the primary winding by giving a rotary motion to the rotor, since such a motion would affect both the field and the windings to the same extent.

The lap winding being located on the rotor has a fixed speed with respect to the rotating field also, and therefore the magnitude of the E.M.F. between a pair of half brushes is independent of the speed of the armature and depends solely on the relative positions of a pair of half brushes. This was confirmed by the readings of a voltmeter connected across the brush pair B_3 S_3 with the primary excited, the secondary windings disconnected from the brush-gear, and the rotor driven at various speeds by an auxiliary motor. The periodicity of the E.M.F. between the brush pair B_3 S_3, however, does depend upon the speed of the rotor. This is explained as follows:—

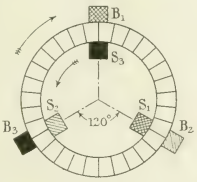


FIG. 3.

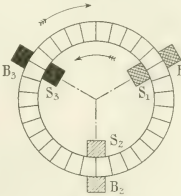


FIG. 4.

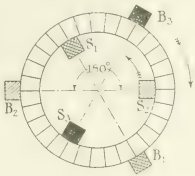


FIG. 5.

B_1, B_2, B_3, are fixed to one rocker moving in the direction of the arrow from left to right. The half brushes S_1, S_2, S_3, for convenience shown on the inside of the commutator, are fixed to the other rocker, which moves from right to left. The ends of one phase of the secondary winding are connected to brushes B_1 and S_1, those of the second phase to B_2 and S_2, and the ends of the

Assume the brushes to remain fixed with respect to one another, say in the position shown by Fig. 5. The brushes have no rotary motion due to the rotor. With the primary winding excited, the primary field rotates synchronously in a direction which depends on the sequence of the phases. If the rotor is driven by an auxiliary motor in a direction opposed to that of the

field, then the speed of the field in space will depend solely on the speed of the rotor, and when the latter is driven at synchronous speed the field will stand still in space. Under these conditions the lap conductors between any pair of half brushes are permanently under one definite part of the field, with the result that the E.M.F. between the pair of half brushes is of zero periodicity. When the rotor is at standstill, the E.M.F. is of fundamental frequency.

To confirm this statement the rotor was driven at half synchronous speed and an oscillograph record taken of the brush injected E.M.F., at the same time using the supply E.M.F. as a reference. Fig. 6 shows these

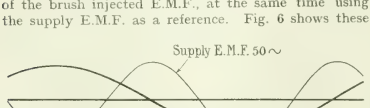


Fig. 6.

two E.M.F. waves and it is seen that, since the fundamental is a 50-period wave, the brush E.M.F. gives a 25-period wave.

With regard to the secondary winding located in the stator slots, the magnitude of the E.M.F. between the two ends of either phase, and also its periodicity, depend on the rotational speed of the rotor, since, as has already been pointed out, the speed of the primary field relative to space, and therefore relative to the stator conductors, depends entirely on the speed of the rotor. A voltmeter connected across the two ends of one of the stator phases, when the primary was excited with the rotor revolving, gave a zero reading at synchronous speed, and two equal readings for speeds below and above synchronism by equal amounts.

Fig. 7 shows an oscillograph record of the E.M.F. across the ends of one of the stator phases, the

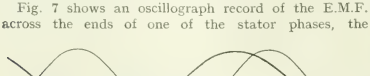


Fig. 7.

brush-gear being entirely disconnected with the rotor driven by an auxiliary motor at one-quarter of the synchronous speed. The fundamental wave, having a frequency of 50, shows the frequency of the induced secondary E.M.F. to be 37·5 periods per second.

From what has already been said, it will be seen that when the motor is operating as a commutator motor, the frequency of the injected E.M.F. between a pair of brush terminals is, at every instant, equal to that of the induced E.M.F. between a pair of stator phase terminals, their phases and magnitudes being possibly unequal. Referring to Figs. 3, 4 and 5, it is noticed that in changing from the position in Fig. 3 to that in Fig. 5, the magnitude of the injected E.M.F., $B_1 S_1$ say, goes from a high value through zero to a high value again and at the same time the brush polarity changes sign.

With regard to the induced E.M.F. between the two ends of a stator phase, this changes from a high value

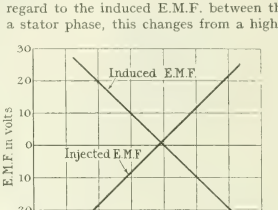


Fig. 8.

at sub-synchronous speeds to zero at synchronous speed, and to a high value again at super-synchronous speeds. At the same time, since the field rotates in opposite directions to the stator conductors for speeds below and above synchronism, the polarity of the stator phase terminals changes as the rotor speed passes through synchronism.

Figs. 8 and 9 show the relative magnitudes and polarity of these E.M.F.'s plotted against the actual motor speed. It is noticed that the induced E.M.F.

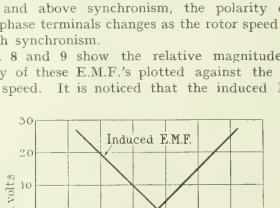


Fig. 9.

predominates at low speeds, whilst the injected E.M.F. predominates at high speeds, and that the brush polarity passes through zero and changes sign below synchronous speed. Fig. 8 is for the motor operating on its normal voltage at no load, and Fig. 9 is for the motor operating against full-load torque. In Fig. 8 the induced E.M.F. was determined in relation to the speed, and the injected E.M.F. to the position of the brushes, the latter position being subsequently calibrated in terms of the no-load speed. The reason for this calibration is as follows :—

The injected E.M.F. can be measured only by disconnecting the brush leads from the secondary phases

and, of course, under these conditions the motor cannot rotate. However, by carefully marking the brush rockers in every brush position for which an E.M.F. reading is obtained, the brushes can be reset to these marks when the motor operates on no load as a commutator motor, and the corresponding speeds can be obtained. In this way, brush position/E.M.F. readings are converted into speed/E.M.F. readings.

Now, although the brush position for zero injected E.M.F. is fixed in space, this brush position cannot correspond on load to as high a speed as it does on no load, since, as in the case of a direct-current shunt motor, the speed falls as the load increases. Thus, on no load (Fig. 8) zero injected E.M.F. corresponds to about 965 r.p.m., whilst for full-load torque (Fig. 9) it corresponds to about 880 r.p.m.

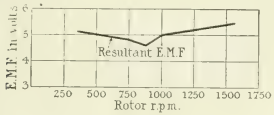


FIG. 10.

Again, whilst the injected E.M.F. curve is always symmetrical about a " brush position " axis, it is unsymmetrical about a " speed " axis. Thus the required decrease in the distance between pairs of half brushes in order to raise the speed from 500 r.p.m. to 700 r.p.m. is less than the required increase in the distance between them to raise the speed from 1 300 to 1 500 r.p.m.

One serious disadvantage of these shunt commutator motors is their liability to hunt. This would appear to be due to the shape of the resultant E.M.F. curve (Fig. 10).

The induced and injected E.M.F.'s act in opposition

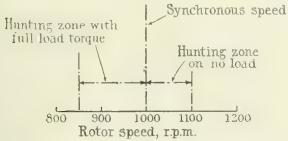


FIG. 11.

NOTE.—Speed variation attains its maximum of 1·0 per cent approximately when mid-zone speed is reached.

on the lap-secondary circuit and the approximate form of the resultant E.M.F. curve is shown in Fig. 10, which is derived from Fig. 9 on the assumption that the phase difference between the induced and injected E.M.F.'s is negligible. This resultant E.M.F. controls the circulating current in the lap-secondary circuit.

With the motor working against any given constant torque the speed corresponding to minimum circulating current is fixed; consequently, as the brushes are moved to increase the speed from a low value, the speed will ultimately be reached at which the circulating current is a minimum. Assuming no further brush movement the speed should remain at this value, but if, due to any cause whatever, the speed should change slightly the current will change by a relatively large amount and the motor will commence to hunt, a fall in speed causing an accelerating torque, and an increase in speed a retarding torque. A small brush movement to either side of this critical position enables the motor to run at a nearly constant speed, but the fact remains that for all loads there is some speed at which hunting takes place.

Fig. 11 shows the limits between which speed variations can be detected both for no load and for full-load torque operation. The speed at which hunting becomes a maximum is lowered as the torque is increased, the reason being that the minimum value of the circulating current moves down the speed scale as the torque is increased, as has already been pointed out. On no load, hunting takes place above synchronous speed, and this may be explained by the fact that the curve in Fig. 10 is much flatter on no load than it is on load.

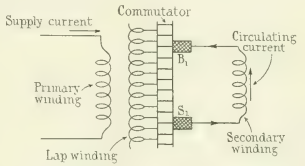


FIG. 12.—Circulating current at sub-synchronous speed.

Diagrammatic arrangements of one phase are shown in Figs. 12 and 13 and these show the circulating current for speeds below and above synchronism.

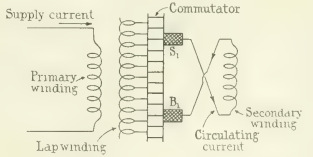


FIG. 13.—Circulating current at super-synchronous speed.

The question of commutation is important in this type of machine because of its bearing on the limiting output of the motor. The motor under discussion in this paper has 6 poles with a maximum output of 15 b.h.p., that is, 2·5 h.p. per pole, and the armature carries a 6-pole lap winding, with probably not more than one turn per commutator segment, the time of commutation being 0·0004 second at 1 500 r.p.m.

Similar motors are built with 12 poles and a maximum output of 75 b.h.p., that is, 6·25 h.p. per pole.

As will be noticed from the following remarks, and

provided that the number of poles can be increased, there is no reason why motors of a much larger output should not be built. Mechanical considerations with respect to the size of the brush-gear and the commutator diameter, will always prevent the number of poles being very large, so that there is an upper limit to the output of this type of motor. It has been suggested that the output per pole could be raised to 20 h.p., but this is doubtful unless means for assisting commutation can be provided.

At any speed, other than synchronous speed, the lap conductors between any pair of half brushes carry current which varies with time, according to a sine law approximately. Assume that the brushes are in the position shown in Fig. 3, with full-load torque and that the rotor speed is 500 r.p.m.

Let I = maximum value of the current per conductor in the lap winding.

Then $I \sin \omega t$ = instantaneous value of the current in a coil about to be short-circuited, where t is the time that elapses between the instant of zero current and the instant the coil reaches the brush.

Since the currents fed from the commutator to the three phases of the secondary winding have a phase-difference of 120 degrees and neglecting the time of commutation, which is small, the current carried by the coil after being short-circuited is

$$I \sin (\omega t + 2\pi/3)$$

Assuming commutation to take place according to a straight-line law and that the change of current in the time of commutation = i,

then $$i = I\{\sin \omega t - \sin (\omega t + 2\pi/3)\}$$

and the voltage necessary to counteract the E.M.F. due to this change is given by

$$e = Li/t'$$

where L = coefficient of self-induction of the coil,
and t' = time of commutation.

Now either pair of half brushes can be regarded as a source of single-phase E.M.F., circulating current through the external circuit (composed of the particular secondary phase winding connected across that pair of half brushes) and the internal circuit consisting of the particular portion of the lap winding between that pair of half brushes.

This conception enables the value of the current i to be readily estimated when it is remembered that the maximum value of i is obtained when

$$I \sin \omega t = 0{\cdot}866\, I$$

and $$I \sin (\omega t + 2\pi/3) = -0{\cdot}866\, I$$

or $$i = 1{\cdot}732\, I$$

Assuming the R.M.S. value of the circulating current to either of the secondary phases to be 120 amperes at 500 r.p.m. with full-load torque (see Fig. 31), and since there are three sets of brushes in parallel, the current fed from either pair of half brushes is 40 amperes (R.M.S.) or 56·4 amperes (maximum).

Thus $I = 56{\cdot}4$ amperes
and $i = 97{\cdot}6$ amperes

The particulars of the lap winding are :—

Number of armature slots	= 54
Number of coil sides per slot	= 6
Total number of armature coils	= 162
Number of commutator segments	= 162
Brush width	= 2 segments
Number of turns per coil	= 1·0
Estimated value of L	= 720×10^{-8} henr
Time of commutation (500 r.p.m.)	= 0·0012 second

Thus $$e = \frac{720}{10^8} \times \frac{97{\cdot}6}{0{\cdot}0012} = 0{\cdot}6 \text{ volt}$$

The brush position affects the value of e because i alters the speed of the rotor and thereby the time c commutation. The value of the circulating curren also changes with the speed, but from Fig. 31 it i seen that 120 amperes (R.M.S.) is possibly as large current as is likely to flow, for any speed, with ful load torque. If the same current were dealt wit at 1 500 r.p.m., then, owing to the decreased time c commutation, this voltage would reach a value c

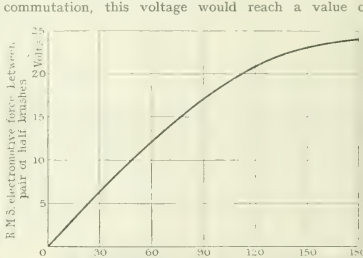


FIG. 14.

1·8. These are the maximum values of e since th greatest possible change in the current has bee considered. The next point to be considered is th transformer E.M.F. generated in a short-circuited coi by the field flux. It has already been pointed out tha the magnitude of the E.M.F. across a pair of hal brushes is independent of the speed of the rotor, bu that its frequency does depend upon the speed an is equal to the supply frequency at standstill and i zero at synchronous speed.

Fig. 14 shows the magnitude of the E.M.F. acros a pair of half brushes in relation to the "electrical angle between them, when the primary is supplie with three-phase current at the normal pressure Over the first portion of this curve the E.M.F. ca be assumed to be proportional to the number of con ductors between the pair of half brushes and, sinc there are 324 conductors in the lap winding as a whole there are 108 conductors per pair of poles. Thu there are 54 conductors in series between a pair o half brushes when they are 180 electrical degrees apart It is estimated, therefrom, that the R.M.S. value o the voltage induced in the lap winding per turn o

coil is 1·41. The maximum value of the voltage which can be induced in a short-circuited coil is therefore 2·0 volts. The transformer E.M.F. in any short-circuited coil will vary from this value to zero, the actual value for any particular coil under a particular brush depending upon the relative positions of the field flux and the brush at the instant the coil reaches the brush.

Assume a pair of half brushes to be 120 degrees

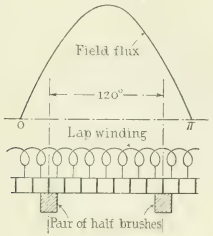


FIG. 15.

apart as shown in Fig. 15. The E.M.F. between them will be a maximum at the instant when the field flux is mid-way over the phase. At this same instant the transformer short-circuit E.M.F. in a coil under a brush must be less than its maximum value. The transformer short-circuit E.M.F. in one coil may be regarded as lagging by 60 degrees relatively to the E.M.F. between the brushes, whilst that in the other coil is leading by 60 degrees.

lating current. In the same way the transformer short-circuit E.M.F. acts against the circulating current and, therefore, is considerably out of phase with the E.M.F. due to the change in the circulating current. Thus successful commutation depends upon being able to design the motor so that the resultant E.M.F. in the short-circuited coil does not exceed a value which can be safely dealt with by the brush contact resistance. Commutation also varies with the distance between the brushes and the speed of the motor, and experiments are now being carried out on commutation under various conditions. It is hoped to publish these results at an early date.

(*Note.*—The E.M.F. due to the change in the circulating current, that is $-Li'$, cannot be represented by a vector in a diagram showing the phase relationship between quantities having a periodic time different from that of the time of commutation. However, since the E.M.F. due to the change in the circulating current is proportional to the change in the current, the vector representing it has been drawn in the same direction as the current vector. It must be remembered, however, that the changes in the time of commutation do not bear any definite relationship to the changes in the periodicity of the transformer short-circuit E.M.F.)

The transformer E.M.F. in a short-circuited coil is not affected by the rotor speed, so that it is present at synchronous speed. However, at synchronous speed the field stands still in space and, therefore, the short-circuit E.M.F. and current in coils passing any given brush will be of constant magnitude, which will depend upon the relative position of the field and that brush. It should be noted that when the field comes to rest it may occupy any space position with respect to any brush, since there is nothing to force the field to come to rest in any particular space position.

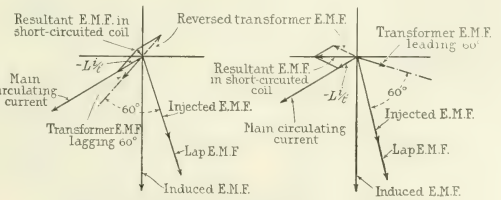


FIG. 16 (see also Fig. 27).

The vector diagrams showing the relative phases and magnitudes of the E.M.F.'s in the short-circuited coils due to the change in the circulating current and the transformer action are shown in Fig. 16. These diagrams also show the magnitude and phase of the resultant E.M.F. in the coils short-circuited by both the half brushes.

As has already been pointed out, for sub-synchronous speeds the injected E.M.F. acts against the circu-

Fig. 17 shows a case where the load is supposed to be of such a magnitude that the brushes are 180 degrees apart when synchronous speed is reached. The brushes B_2 S_2 are not in a position for obtaining successful commutation, but it will be noticed that they are in a position where the E.M.F. across them is zero, so that there is no circulating current to deal with; the current due to the short-circuit E.M.F. is, however, a maximum. Under these circumstances

the total circulating current is supplied by the other two sets of brushes. Of these two sets, one is in a much more favourable position for good commutation than the other, and it is quite possible that a kind of selective commutation will take place and that the greater portion of the current will be fed from the most suitably placed set. This actually takes place (see Table 1) and, therefore, commutation at synchronous speed is as difficult as, if not more difficult than, at any other speed, since the whole current is dealt with by the brushes of one phase. In this particular motor it is probable that commutation is almost as severe a proposition as one would care to deal with by brush resistance alone, and this makes it doubtful whether the output per pole for this class of motor can be raised very much above that already proposed by the manufacturers.

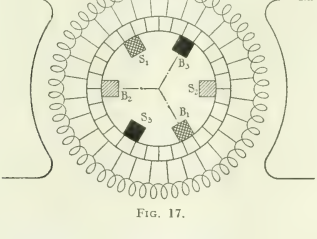


FIG. 17.

Table 1 shows the readings given by three ammeters, one being placed in each of the three separate lap-

TABLE 1.

Speed	Half Full-load Torque Lap-secondary Circulating Current		
	Phase I	Phase II	Phase III
r.p.m.	amperes	amperes	amperes
300	50	48	48
850	30	29	56
1 500	50	38	49

secondary circuits. It will be noticed that a certain amount of unbalance occurs at all speeds; this is probably due to small differences in the brush settings which cause slight differences in the three lap E.M.F.'s. The lack of balance is much more noticeable at 850 r.p.m. than it is at either 300 r.p.m. or 1 500 r.p.m., and this is undoubtedly due partly to selective commutation and partly to the lower effective resistance of the lap-secondary circuits in the neighbourhood of synchronous speed. Readings cannot be obtained near synchronism due to the fact that the periodicity of th current becomes low enough to enable the ammete needle to follow its variations, but it is practicall certain that the lack of balance would be most pro nounced at synchronous speed. This lack of balanc is not reflected into the primary lines; ammeters i these lines showing an almost perfect balance unde

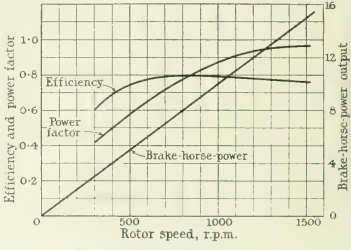


FIG. 18.—Torque maintained constant while speed was varied by brush adjustment.

all conditions of operation. This is probably due t the fact that the primary winding rotates with respe to the secondary winding and that each set of brush is connected to all the lap conductors, since the lap a closed winding.

Fig. 18 shows the performance of the motor whe working against full-load torque. It will be notice that between 500 r.p.m. and 1500 r.p.m. the efficienc and power factor are both quite good.

In order to ascertain whether the centre line of t brush-gear coincided with that of the primary-seconda phases, the primary was excited with the seconda phases disconnected from the brush-gear. An oscill graph record was then taken to show the phase relatio

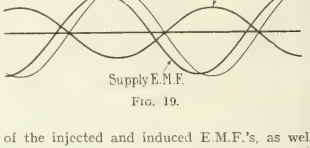


FIG. 19.

ship of the injected and induced E.M.F.'s, as well a that between these E.M.F.'s and the supply E.M.I Fig. 19 shows that the injected and induced E.M.F. are practically in phase (one was reversed to accentua any difference) and that they are slightly out of pha with the supply E.M.F. This is exactly what woul be expected on no load for a symmetrical setting the brush-gear. This is the normal arrangement of t brush-gear and existed when the tests shown in Fig. were made.

The vector diagram corresponding to Fig. 1

where the centre line of the brush-gear coincides with that of the primary-secondary phases, is shown in Fig. 20. If the motor is operating at some constant speed on no load, then the fractional distance α between pairs of half brushes is fixed, and if E_L is the maximum E.M.F. generated between a pair of half brushes, then αE_L will be the magnitude of the injected E.M.F. Whatever the speed, the power factor of the supply current is bound to be low, since the magnetizing current

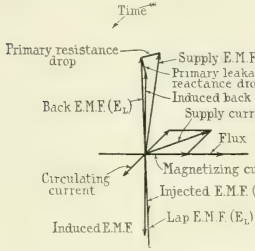


FIG. 20.

is a relatively large proportion of the supply current. Thus the induced and injected E.M.F.'s will be nearly in phase with one another and slightly out of phase with the supply E.M.F. In Fig. 20 it is assumed, as stated on page 328, that there is no leakage between the lap and primary windings.

If the motor is loaded, especially on the higher speeds, the power factor of the supply current improves, because

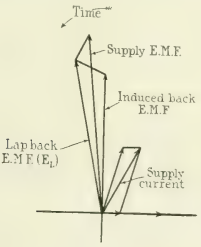


FIG. 21.

the magnetizing current is now a small proportion of the supply current, and the phases of the various E.M.F.'s become as shown in Fig. 21. Here it is noticed that the phase difference between E_L and the induced E.M.F. is considerable.

With respect to both Figs. 20 and 21, if the centre line of the brush-gear is displaced from that of the primary-secondary phases by an angle σ, then the injected E.M.F. vector will be displaced from the lap E.M.F. vector by an equal angle. This angle will either lead or lag, depending on whether the displaced centre line leads or lags.

Figs. 22 and 23 show the supply current and power factor as functions of the rotor speed when the motor operates against full, three-quarter and half-load torques.

With regard to the supply current, it is noticed that the point of minimum current is displaced from synchronous speed by an amount depending on the torque, in a manner similar to that described in the case of the circulating current. It so happened that under each of the three loads a constant watt input had been obtained, and lines have been drawn showing the supply current and power factor for this constant input. To obtain the necessary speeds in each of the three cases, in order to keep the input constant, three different

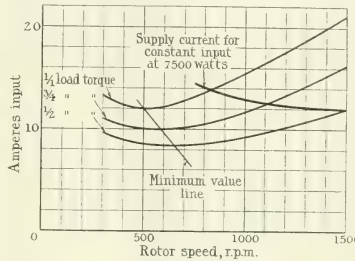


FIG. 22.—Supply current curves.

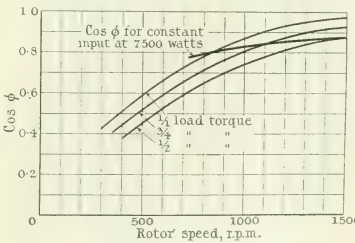


FIG. 23.—Power factor curves.

brush settings were necessary. The inference from these facts is that although, with the brushes permanently fixed in any given position, the motor operates in a similar manner to an ordinary induction motor, the brush-gear setting fixes the no-load speed as well as the diameter and position of the circle.

Fig. 24 has been drawn to illustrate this point and should be compared with Figs. 22 and 23. In Fig. 24 the vectors OA, OB, and OC show the magnitude and

power factor of the supply current for different speeds. This variation in the diameter and position of the circle forms the subject-matter of a later portion of these notes.

In order that the action of the motor may be readily understood vector diagrams have been drawn. Reference to Figs. 12 and 13 will show that the ampere-turns of the lap winding magnetize at sub-synchronous speeds, since the circulating current through them acts with the supply current, and demagnetize at super-synchronous speeds, since the circulating current through them then acts against the supply current; also that the ampere-

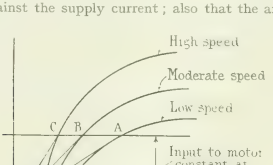


FIG. 24.

turns of the secondary winding demagnetize at all speeds, and that the motor normally works with the centre line of the brush-gear coincident with that of the primary and secondary phases.

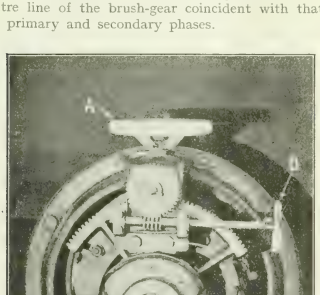


FIG. 25.

Fig. 25 shows an arrangement whereby the brush-gear was altered so that, in addition to the handle "A" which controls the magnitude of the distance between pairs of half brushes (referred to as "a," and Fig. 5 shows that a reaches unity when the brushes are

180 degrees apart), a further handle "B" controls the position of their centre line and enables it to be moved either in advance or behind the centre line through the

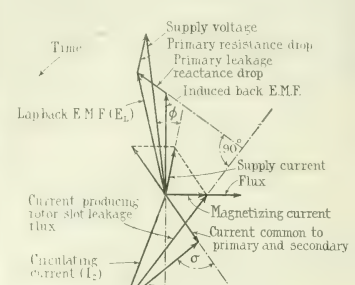


FIG. 26.—Load vector diagram.

primary and secondary phases by a variable angle referred to as "σ." This enables the voltage between a pair of brushes to be selected as regards both phase and magnitude when compared with the lap voltage E_L.

Fig. 26 shows the phase relationship between the vectors in either phase at sub-synchronous speed, a being the distance between the brushes and σ the retarded angle between the centre-line of the brush-gear and the primary phase. A retarded angle is obtained by moving the brush centre-line in the direction of rotation of the primary flux-wave, and this causes the magnetizing ampere-turns of the lap winding which are proportional to aI_2 to lag by an angle σ

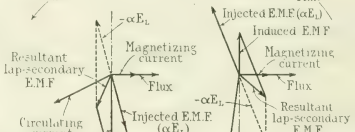


FIG. 27.

relatively to those of the primary phase. The angle ϕ shows the power factor of the supply current.

The current in the lap winding as a whole is zero because the sum of three equal sine currents displaced by 120 degrees is zero. Thus the current flowing between

a pair of half brushes is confined to the lap conductors between this pair of half brushes, and the ampere-turns are therefore proportional to αI_2 since the number of turns between the pair of half brushes is proportional to α.

Fig. 27 shows the effect of speed upon the power factor of the circulating current when the angle σ is zero. It should be noted that, with any fractional

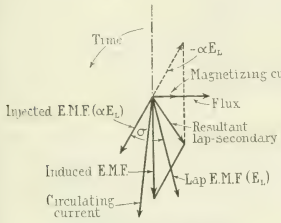


Fig. 28.

distance α between the brushes, the injected E.M.F. is equal to αE_L, E_L being the maximum E.M.F. obtainable between the brushes; also that the injected and induced E.M.F.'s are in opposition at all speeds and that whereas a large retarded angle σ would improve the power factor of the circulating current at low speeds, a small angle will be required if a high power factor is required at high speeds. This particular diagram

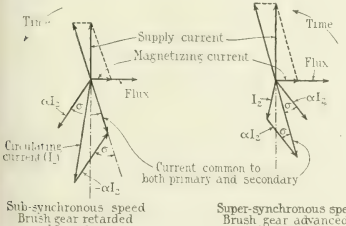


Fig. 29.

represents the conditions under which the motor operated when the test-results shown in Fig. 18 were obtained.

Fig. 28 shows the improvement in the power factor of the circulating current at low speeds by the introduction of the retarded angle σ.

Fig. 29 shows the power factor of the supply current and brings out the fact that, owing to the demagnetizing effect of the lap ampere-turns at high speeds, a leading angle σ is required to obtain a high power factor.

Fig. 30 shows the results of tests made on the motor when the centre line of the brushes was adjusted to obtain unity power factor at all speeds against full-load torque. These tests bear out the statement made with respect to Fig. 29, since the angle σ, which was a fairly large retarded angle at 500 r.p.m., decreased as the speed was increased and became a leading angle of moderate size at 1 500 r.p.m. Under these con-

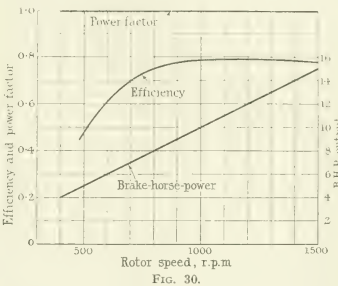


Fig. 30.

ditions the speed-range which gives a reasonable efficiency is from about 800 r.p.m. to 1 600 r.p.m. This shortening of the speed-range is a disadvantage and should be compared with the results shown in Fig. 18.

Fig. 29 also indicates that the supply current increases as the speed increases, and that the circulating current decreases. Fig. 31 shows the results of tests made to verify these points, the conditions being the same as existed when the tests shown in Fig. 30 were carried out.

From the vector diagrams it is seen that when the

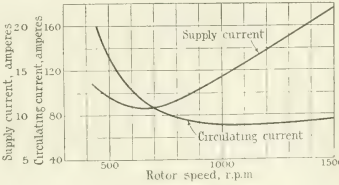


Fig. 31.

angle σ is zero, the phase of the resultant lap-secondary E.M.F. changes considerably as the speed is increased. This, together with the fact that its magnitude also changes, causes the form of the circle diagrams to approximate to that shown in Fig. 32. Thus if the brushes are permanently set so that the motor runs at a sub-synchronous speed on no load, then, by loading the machine and plotting the supply current, a portion of the circle diagram can be drawn and the circle will

conform to that shown for a sub-synchronous speed in Fig. 32. Similarly, if the brushes are permanently set so that the motor runs at a super-synchronous speed on no load, it is possible, from a series of supply-current readings, to plot a portion of a circle corresponding to that shown for a super-synchronous speed in Fig. 32.

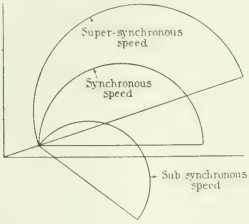


FIG. 32.—Circle diagrams for motor on load.

When the angle σ is adjusted to give unity power factor at all speeds, the phase of the resultant lap-secondary E.M.F. remains fairly constant and its magnitude also does not vary much. This causes all the circles to lie above the horizontal (see super-synchronous circle in Fig. 32) and to vary but little

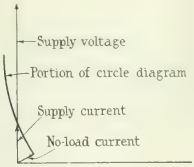


FIG. 33.—Portion of circle diagram for motor operating against full-load torque. Angle σ constant at a value which makes the power factor unity.

in diameter. Thus, suppose that the brushes have been set so that the motor is operating against full-load torque, at a sub-synchronous speed, with the angle σ adjusted to make the power factor of the supply current unity. If, now, the load is increased, readings of the supply current can be obtained and a portion of the circle diagram obtained, as shown in Fig. 33. Again, suppose the brushes to be set and the angle σ adjusted so that the motor operates on unity power factor at a super-synchronous speed against full-load torque then, by increasing the load, a new circle diagram can be obtained, and this new circle must cut the supply voltage vector in a similar way to that shown in Fig. 33. This leads to the assumption that, under these conditions, the circles for all speeds lie above the horizontal instead of conforming to Fig. 32 where the angle σ is maintained at zero.

The method, by which the performance of the motor may be estimated from the measured resistance and reactance of its component parts, has been outlined by H. K. Schrage.* These conclusions were borne out by actual tests on the motor.

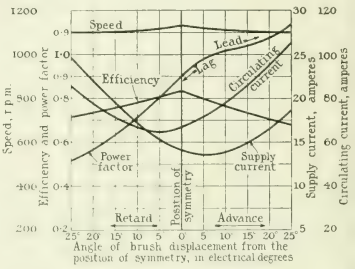


FIG. 34.

Fig. 34 shows how the performance of the motor is affected by varying the angle σ, the angle of displacement of the brush-gear centre line, when the motor operates against a constant torque equal to three-quarters of full-load torque, at a speed just above synchronism. The constant fractional distance a between pairs of half brushes was such that the motor ran at 1 100 r.p.m. It will be noticed that by varying the angle σ a small variation in speed is produced.

In conclusion the author wishes to thank Professor E. W. Marchant for the great interest he has taken in the preparation of these notes and for many valuable suggestions. The author's thanks are also due to Messrs. D. I. Dawbarn, E. W. Young and F. P. Best for their assistance in making the tests and working up the results, and to whom Fig. 34 is entirely due.

* *E.T.Z.*, 1914, vol. 35, p. 89.

PROPERTIES AND USES OF MICAS.

(Report received from the British Electrical and Allied Industries Research Association, 18th February, 1922.)

Introduction.

This investigation was commenced by the Institution of Electrical Engineers, and is now under the direction of the Electrical Research Association.

A great deal of work has been done, and the investigation is by no means completed, but as some of the results already obtained should be of immediate value, this Report is issued.

Schedule A.

Trade Description of Micas and Corresponding Characteristics.

Class	Mineralogical Group	General Characteristics	Relative Hardness
Ruby	Muscovite	Colour, pale reddish brown (ruby red in plates 15 mm thick)	Hard
Soft White	"Altered" Ruby Muscovite	Slightly yellowish. Slightly calcined appearance	Softer than ruby
Silver	"Altered" Muscovite	Slightly calcined (silvery) appearance. Wavy surface	Hard as ruby
Green	Muscovite	Inclined to have internal cracks	In greater crystalline tension than ruby
Brown	Muscovite	Ditto	Ditto
Amber	Phlogopite	Colour, very pale yellow to dark or opaque. Wavy surface. Great expansion at right angles to laminations	Soft
Altered or Silver Amber	Phlogopite	Naturally altered amber. Colour same as unaltered amber, but more metallic. Silvery and opaque	Softer than unaltered amber
Black Amber	Biotite	Very dark green or brown in thin sheets (about 0·003 in.). Black and opaque in thicker plates (0·01 in. and up)	More brittle than amber
Lithia Mica	Lepidolite	Light mauve, yellow greyish white or white. Will not stand heat and fuses at ordinary flame temperature	Very hard and brittle

Sub-divisions.

Any class may, if required, be sub-divided as follows:—

Variety	Quality
Clear	Free from stains and spots (inclusions) — A. Free from all defects. B. Contains gaseous inclusions.
Slightly Stained	Free from spots (inclusions).
Stained	Free from spots (inclusions).
Heavily Stained	Free from spots (inclusions).
Spotted	With solid inclusions.

Classification of Micas.

Great difficulties have been met with owing to the absence of uniformity of nomenclature for the different kinds of mica. Considerable attention has therefore been given to the classification. The classification recommended by the Association is set forth in Schedule A, and it is urged that all investigators making tests on mica should adopt the nomenclature therein. Much of the work done in the past has suffered in value owing to the absence of adequate information as to the exact nature of the material tested. This will be appreciated when it is noted that the Association finds there are 10 principal classes of mica and a large number of sub-varieties.

A large collection of representative micas has been prepared from materials supplied by Messrs. F. Wiggins & Sons and Messrs. Startin & Co., and the specimens have been named in accordance with Schedule A. This collection has been presented to the Institution of Electrical Engineers.

Specifications for Mica.

It has been found that the tests and characteristics required for mica which is intended to be employed for the various industrial uses have received very little attention in the past. It often happens, for instance, that the mechanical characteristics of mica are of much greater importance than its electrical properties, but so far as has been ascertained these have seldom received much consideration, and there have been no generally recognized tests for mechanical properties. The suitability of the different kinds for high-grade electrical work has never been investigated in a systematic way with a view to the definition of tests which can be applied for the purchase of materials for such purposes.

Specifications for mica too often fall back on the requirement that "only the best clear ruby mica shall be used," the obvious reason being the non-existence of any recognized tests to prove the suitability of the various classes of mica which might be available for the purpose in question.

In view of this absence of recognized tests, it has been found impossible to define with precision the test clauses suitable for a general Mica Specification, and the only course has been to schedule the principal uses to which mica is to be put, and for each of these uses to define the special characteristics required in the mica, leaving to further research the task of elucidating the standard tests to be applied for proving such characteristics.

Special attention has been given to the requirements of mica and micanite for commutators, and this is dealt with below.

Identification Tests.

These have been studied and are classified in Schedule B. A quantity of data has been obtained, but further study is required.

Preliminary researches have been made on the surface hardness of different varieties of mica, and whilst these tests are not promising as a means of classification according to kind, they may be of value in classifying according to use. Hardness and other mechanical tests are receiving further attention.

Schedule B.

Identification Tests for Micas.

The following are identification tests which may be applied to micas described in Schedule A :—

Calcining	Temperature at which calcination occurs.
Colour Characteristics	Colour by diffused daylight (through thickness 0·5 mm) in a direction normal to plane of plate. Nature of surface. Foreign matter (inclusions).
Optical	Axial angle and relation of it plane to the plane of symmetry. Percentage absorption of light
Chemical	Nature of surface after acid treatment.
Electrical	Dielectric constant (specific inductive capacity). Dielectric loss.

Selection of Micas.

The numerous uses of mica in the electrical industry as, for example, in commutators, condensers, sparking plugs, and pyrometers, have been classified, together with the appropriate characteristics so far as these are known.

A study of the above has shown already that certain kinds of mica are peculiarly suitable for certain purposes, and that the range of kinds suitable for some purposes is larger than has been recognized. Preliminary suggestions are made in Schedule C which should prove of immediate service, but much further research is necessary to complete the schedule, and to establish definite limits for purchasing purposes.

Mica and Micanite for Commutators.

The leading manufacturers of commutating machinery have furnished full information of their practice and experience, and this has been reviewed in detail. A number of representative large users of commutating machinery have also been approached, their experience ascertained and opinions carefully sifted. As a result the Association is now able to present a comprehensive statement of facts ascertained. It is doubtful if any further conclusions can be reached on the evidence now available, but the Association has still in hand experimental work which should throw further light on some of the problems which have to be faced.

Commutator Segment Separators.

Materials and Construction Employed.

Pure mica.—The material used for pure mica commutator segments is mostly stained and spotted, brown and green, light and dark in colour. Soft white and amber is also largely used. Separators in one length are obtainable up to about 16 inches or more, but on first cost it pays to use built-up material or micanite when the length needed exceeds about 6 inches. In the smaller sizes pure mica is cheaper than micanite.

Built-up mica.—With built-up separators, the pieces being stiff, a good deal of adhesive is required, and it is questionable if there is much benefit as compared with the use of micanite specially made for the purpose. The built-up segment is preferred by some designers who have had trouble with micanite. It is essential to use a minimum of adhesive so that the material shall not "give" when hot.

Micanite.—Micanite separators should not contain more than 2 or 3 per cent of adhesive, whereas ordinary micanite may contain 10 to 15 per cent. The micanite is made from clear mica, and from amber mica where called for. There is no reason why micanite for separators should not be made from spotted and stained mica, supplies of which are readily available. The price of clear mica is 100 per cent more than spotted and about 25 per cent more than stained.

Flush and undercut mica separators.—Some makers undercut all commutators, but flush segments are still largely employed, especially on small machines, where hard brushes are used. Commutation on most modern machines is so good that the machine may run for years on the first undercut. On important machines, however, where soft brushes are generally to be found, some makers use soft separators, so that, even if the commutator is worn down and undercutting neglected for a time, trouble will not ensue, and they are willing to pay the extra cost of amber mica to ensure this result.

Where flush separators are used, the buyer sees the material is uniform and not too hard. The danger from hard spots is greatly reduced where the separators are built up in any way.

Further research is in hand on the abrasive hardness of mica in order to determine what micas will give satisfaction with flush separators.

Mica versus micanite.—From information obtained from large users and leading manufacturers of commutating machinery, the following conclusions have been arrived at with regard to the relative merits of the use of pure mica, built-up mica, or micanite.

All three kinds of separators can be obtained finished to a sufficient degree of accuracy for the purpose. In general, $\pm$ 1 mil can be guaranteed without difficulty on mica segments and $\pm$ 2 mils on built-up mica and micanite, but micanite is bought also under guarantee of $\pm$ 1 mil. Pure mica makes the best mechanical job, is less liable to flake or change under the influence of heat. Micanite properly compressed and with a minimum of adhesive is successfully and extensively employed in both large and small machines. It is cheaper, except in small sizes. The cost per square foot varies but little with the size, so that in large sizes considerable saving may be effected. It is less liable to give trouble through hardness and is free from hard spots. Difficulty has been experienced where oil has got on to the micanite, as the oil and adhesive together get carbonized, necessitating taking the commutator apart to remedy the defect. This applies also to built-up mica. This trouble, however, is one within the province of the designer to remedy and the user to avoid.

Schedule C.

Micas Suitable for Specified Purposes.

Commutators.	
Flush segments ..	Amber and silver amber. Green and brown.* Certain grades of soft white.
Undercut segments	Any sound micas which will cleave readily.
Rings and cones ..	Black amber.* For further details see following report.
Wrappings, channels, tubes and washers.	
Extra high tension	7 000 volts and over: Ruby clear A and B. Below 7 000: Any mica not spotted.
High frequency ..	—
Condensers.	
High frequency (above 2 000)	Ruby clear A. Green or brown clear.* Ruby clear B, considered not suitable.
High-temperature purposes.	
Spark plugs ..	Ruby clear, ruby slightly stained or stained.*
Pyrometers ..	Green or brown.* Ruby clear A, and possibly other micas.*
Furnace work ..	*Insulation:* Any mica which has the necessary mechanical characteristics. *Arc resisting:* Muscovite where mechanical requirements predominate. Phlogopite where ability to resist great heat is required.
Heating and cooking	Muscovite where mechanical requirements predominate. Phlogopite where ability to resist great heat is required.
Mechanical and optical.	
Diaphragms ..	Lithia mica. Ruby clear A.†
Windows and spectacles	Any clear mica.
Dials, vanes, and compass cards	Any uniform flat mica.

* Subject to research.
† Subject to research, especially in regard to fatigue.

RINGS AND CONES.

Materials employed.—Rings are sometimes made up of the more flexible grades of mica butt-jointed or lap-jointed, but micanite is the principal material employed, the cones being built up from suitably cut pieces stuck together and pressed hot into shape. The adhesive left in may be of the order of 10 per cent.

The thicker splittings are cut from block, but the thin splittings are the regular article of commerce.

Thin splittings.—Splitting of Indian mica is more cheaply done by Indian labour, before shipment to Europe. It is a trade developed solely for the electrical industry, and the tendency of the individual buyer to play for safety in a matter over which he has no contro and imperfect information, has resulted in the supply consisting almost exclusively of clear mica, whereas for many purposes there is no doubt that stained spotted and dark-coloured material could be used with considerable economy in first cost.

The Association is not prepared to make definite recommendations until the results are available on the nature and incidence of inclusions and impurities in mica from the electrical standpoint, showing their effect as conductors on breakdown voltage, surface leakag and dielectric losses. Research on this is now being put in hand.

DISCUSSION ON

"INDUCTION-TYPE SYNCHRONOUS MOTORS."*

SCOTTISH CENTRE, AT EDINBURGH, 10 JANUARY, 1922.

Mr. C. W. Marshall: I understand that it is a fairly common practice on the Continent to supply the rotors of induction motors of the ordinary type with direct current in order to improve the power factor. As no details of the methods employed have been disclosed, I should be glad if the author would give some particulars.

Mr. A. E. McColl: In the introduction to the paper the author gives one of the principal reasons why we should consider synchronous plant or types of induction motors which have the characteristics of synchronous plant. This reason is the extremely low power factor which has to be tolerated nowadays. In municipal supply, with its condensed distribution area, the practice in the majority of cases has been to adhere to the direct-current supply. The perpetuation of this system for secondary distribution has enabled those municipalities who generate alternating current for primary distribution to secure, by means of the rotary converter and synchronous motor-generator, the higher power factors which are essential to economical working. With district supply authorities, however, the territorial ramifications are such as to preclude the possibility of giving secondary distribution by means of direct current, and adherence to the alternating-current supply usually involves the power authority in all the losses consequent on low power factor. The chief offender in this respect is the comparatively small induction motor where the ratio of mechanical load to rated output is small. I think it is improbable that the synchronous induction motor will displace the ordinary induction motor in this connection, as it becomes difficult to justify the difference in cost on the smaller sizes, and I feel that the static condenser will, on 50-period circuits, successfully meet the com petition of the synchronous induction motor. I am of opinion, however, that this later type has an assured future, particularly in its application in the large sizes to air-compressor drives and loads of an inter mittent nature. Those of us who have endeavoured to improve the power factor of the supply authorities mains will agree with me that any proposition involving additional outlay is very coldly received. Herein lie the chief difficulty in inducing a consumer to instal the type of apparatus which the author has described and until the difference in cost between an ordinary induction motor and the motor described by the autho is lessened, it becomes difficult to secure the adoption of this type of motor. The power supply authorities are, however, quite aware of this aspect of the business and, when the adoption of tariffs involving power factor rebates and penalties becomes uniform through out the country, I foresee that there will be a large demand for the induction-type synchronous motor One great advantage which such a motor has over the ordinary synchronous motor lies in its large startin torque, its pull-out torque, and its capacity to run on the induction-motor characteristic if it should pull out. I take it that there would not be much differenc in price between a synchronous machine and the synchronous induction motor. I should like to ask t what extent the latter would function as a generato if the phase were advanced relatively to synchronism I should also like to know what would be the effec on the supply system if a large synchronous inductio motor were pulled out of step. The disastrous effec when a purely synchronous motor behaves in this manne is well known. I have in mind a 50-period suppl given from an existing 25-period system, the chang

* Paper by Mr. L. H. A. Carr (see page 165).

in periodicity being effected through the medium of a 6 000-kW alternator driven by the type of motor described in the paper. In a case such as this, heavy faults on the 50-period side may prove sufficient to pull the synchronous induction motor out of step. Would the resulting disturbance be as great as one might expect when the drive is effected by an ordinary synchronous motor?

Mr. D. S. Baddeley: The paper deals principally with the type of synchronous motor in which a three-phase winding is used on the rotor. With this form of winding, when running as a synchronous motor, the phases are unbalanced electrically. The Oerlikon Company took out patents for sectionalizing these windings. I should like to know what is the effect on the exciter system of this type of synchronous motor, as it appears that a heavy shock is momentarily thrown on the excitation system in changing over. The author gives the maximum voltage at starting as 2 000 volts. This would appear to be dangerous where unskilled labour is employed. I understand that this type of synchronous motor is very sensitive to any variation in the supply system, and will fall out of step and shut down. What effect would this have in practice? No mention is made in the paper of a synchronous motor manufactured by Messrs. Crompton & Co. This machine employs a two-phase rotor winding with the exciter permanently in circuit. This type of synchronous motor appears to be greatly simplified in its starting gear, as it starts up as an ordinary induction motor, and pulls into synchronism automatically without the employment of any change-over switches, etc. In addition, the liquid starter and the exciter circuits are earthed, thus eliminating any danger from the momentarily high voltage at starting.

Mr. J. F. Nielson: This machine is bound to be considered more and more by the electrical engineer as the question of power factor is brought before the consumer. Power companies are awakening to the necessity of reducing the cost of generation and supply of electrical energy and, as a consumer, I wish that this question of synchronous induction motors had come before my notice very much earlier. At the present time the firm with which I am connected are considering very seriously the question of how the costs of supply can be reduced. The scheme proposed by the power company is that anyone having a better power factor than 0·8, which is taken as a basis, can obtain a reduction up to 20 per cent in the kilowatt charge. On the other hand, he may be penalized if his average power factor falls below 0·8. For example, should the power factor be as low as 0·6, he is penalized to the extent of having to pay 33 per cent extra on the kilowatt charge.

Mr. W. L. Winning: I was particularly impressed by the number of firms in Britain making this type of machine. I was also impressed by the size of some of the motors described, particularly the Continental ones. I note that electrical manufacturers in the United States have not up to the present done anything with this type of machine. I am rather inclined to share the views of Mr. Baddeley with regard to the effect of a pressure of 2 000 volts on the rotor of an induction motor. This voltage entails a larger number of conductors than is usual, and I should think that a rather careful arrangement of these conductors is necessary to prevent breakdown of insulation due to this very high voltage at starting. I should also think that the type of motor described in the paper would call for very careful manufacture on that account. Even then there is a likelihood of trouble in the machine and, in addition, 2 000-volt resistance starters are sources of danger. The exciting voltage is given as 36 volts, but during the starting period it may rise to 2 000 volts or even more, i.e. the machines must withstand a pressure-test of 5 000 volts to meet the usual engineering standards. This naturally makes the design and manufacture of the rotor difficult, and this is perhaps one of the main reasons why the induction-type synchronous motor is not more universally used.

Mr. G. Austin: If power supply engineers are sufficiently far-seeing to offer an adequate inducement to consumers to install synchronous machines, by way of reduced rates for high power factor or otherwise, then it is to the advantage of the consumer to consider the question in the case of motors of fairly large power intended to be run more or less continuously. In common with Mr. Neilson, I should have liked to see this paper a few years ago. During the war, I had in hand two large shipyard installations in Dundee, and, a lower tariff being offered, I tried to gain information about self-starting self-synchronizing synchronous motors. There is no mention in the paper of the cascade self-starting synchronous motor designed by Mr. Hunt. This motor requires no slip-rings except for conveying the exciting current to the rotor. There does not appear to be any advantage in the cascade arrangement in the case of a synchronous motor because the slip-rings, being necessary for the exciting current, might as well be used for rotor starting currents. In the event of the exciter failing, the speed of the machine could, if permitted, rise to twice the normal. I recently saw a machine with single-phase rotor as illustrated in the paper. It was coupled to an air compressor and worked well, but it was sometimes necessary to give the flywheel a turn at starting, showing that there was no reserve of starting torque even for an unloaded machine. The machine with a three-phase rotor which we finally adopted seemed to me to be capable of giving a starting torque, with reasonable current, far in excess of our requirements for an unloaded machine, and it has proved to be thoroughly satisfactory in practice. I examined the Crompton arrangement later when ordering a 650-h.p. machine, and it seemed to me at the time to be quite good. We preferred, however, to adhere to the type already installed. I believe that the two 300-h.p. machines installed at Dundee were the first in this country to be operated automatically by contactor switchgear. There is a distinct advantage in using such switchgear, as it eliminates the human element and is fool-proof. Its extra cost is a comparatively small matter in the total cost of a large machine, and the saving effected at times of light load soon repays the extra outlay. In the 650-h.p. motor referred to, the starting resistances

were connected permanently across the slip-rings; at the synchronizing point the contactors were tripped out of circuit in rotation and the exciter was finally switched on to the rings. As the exciting current is at a pressure of only 30 volts, the current passing through the resistance is negligible. In one of the machines which I saw, the air-gap was very small, and, although the shaft appeared to be strong, if started too quickly the rotor began to oscillate and bump against the stator, thus showing that there was a very strong field in the air-gap.

Mr. H. A. McGuffie: I am interested in this type of motor more from the point of view of the consumer. The question of buying electrical energy on a kilovolt-ampere basis has been raised recently by consumers. I think we are following Continental practice to a great extent. I am also interested in the question of power factor improvement by means other than synchronous machines. I refer specially to the static condenser, which I have found entirely satisfactory. One of these has been installed since 1912 and another from 1915, of 375 kVA capacity. Amongst the advantages of the static condenser may be mentioned the absence of moving machinery, high efficiency and simplicity of operation; and it can be treated like a transformer. I recently inspected one of the machines described in the paper, and I noted that the starting was entirely automatic, being effected by the operation of a push-button. The motor came up to speed without any flicker, and it made no attempt to swing in any way.

Mr. W. J. Cooper: There is probably a very great field for synchronous motors, particularly in the coal-fields. I think that it should be quite possible to co-ordinate the operations of ventilating and pumping, so as to permit of the installation of large synchronous motors, but if consumers are to be encouraged to do this, power supply authorities will have to adopt some method of giving rebates for leading power factors. It is unlikely that leading power factors will become a difficulty as far as the power factor of the system is concerned.

Mr. L. H. A. Carr *(in reply)*: I cannot agree with Mr. Marshall that it is fairly common practice on the Continent to supply the rotors of induction motors with direct current in order to improve the power factor, and I think that he must be mistaken, as the synchronous induction motor, which is what this method of operation amounts to, has been taken up on the Continent (excluding Sweden) only since the armistice.

In reply to Mr. McColl, there is usually little difference in cost between a synchronous motor and a synchronous induction motor; sometimes one is the cheaper, and sometimes the other. The synchronous induction motor will run quite satisfactorily as a synchronous generator if mechanical power is supplied to the shaft, and this type of machine will probably be used in the future in place of the plain induction generator for automatic auxiliary power stations. Its use for this purpose has already been suggested in a number of cases. Speaking generally, the disturbance on a system produced by the falling out of step of a synchronous induction motor will not be so great as would occur with a salien pole machine. Further, the synchronous inductio motor will pull itself back into step automatical and almost instantaneously, immediately the origin cause of the trouble is removed.

Mr. Baddeley states that, with the three-phase rot winding, when the machine is running as a synchrono motor the phases are unbalanced electrically. This not strictly accurate. On the supply side the phas are perfectly balanced. I take Mr. Baddeley's stat ment to mean that the rotor conductors do not a carry the same current when excited with direct curren There is no unbalance of phases, in fact, no pha differences exist in the rotor when it is running synchro ously, neither is there any want of balance in the flux magnetic pull. The only inequality that exists is the distribution of the heating around the rotor periphery but, owing to the good heat conductivity of the roto the temperature-rise is very nearly uniform. Again this, with both the Oerlikon and Crompton method where all the rotor conductors carry the same curren has to be set the fact that, other things being equa such methods of connection require a 12 per cent bigge loss in the rotor to give the same fundamental sin wave of flux, i.e. the same output. In addition, th Oerlikon method unbalances the phases of the suppl when starting up from rest.

I cannot agree that a pressure of 2 000 volts is an more dangerous on the rotor than on the stator. Fro the slip-rings onwards, the rotor starting circuit is usuall ironclad.

Mr. Baddeley is in error in imagining that the syn chronous induction motor is very sensitive to variation in the supply system. As a matter of fact, as I hav shown in my reply to the discussion at Manchester, is less sensitive than a plain induction motor to a dro in the supply pressure. The synchronous inductio motor with exciter permanently connected in circu is not to be recommended since it causes violent fluctua tions in the line during the whole time of starting up in place of the short kick, lasting only some 4 or cycles, when the exciter is switched straight into th rotor circuit at full induction-motor speed.

Mr. Baddeley's remarks in regard to earthing ar quite beside the point. All liquid starters—no matte what the connection of the rotor—are earthed, and wit the 3-pole switch arrangement always adopted whe high voltages are induced in the rotor there is nothin to prevent the exciter circuit from being earthed as wel

In reply to Mr. Winning, and this also refers to Mr Baddeley's remarks, 2 000-volt rotors present no difficult nowadays when used in their appropriate field, i.e. i large machines. These high voltages are generally use only with a 2-bar-per-slot construction in the rotor, th type of construction that lends itself most readily t satisfactory insulation. It is perhaps not generall realized that, with plain induction motors havin capacities of several hundred horse-power, this figure o 2 000 volts in the rotor is approximately reached. Th test voltage of the machine is, as Mr. Winning suggests 5 000 volts when the machine is finished, and corre spondingly more in the course of manufacture.

With reference to Mr. Austin's remarks, cascad

synchronous induction motors have been built under Mr. Hunt's patents, in which both the supply and the direct-current excitation are supplied to the stator. The winding, considered as a three-phase winding, is in two parallels, and the exciter is connected between the two star-points.

Written Communication to the Discussion.

Dr. A. Hay (*communicated*): The paper forms a welcome contribution to a subject which has attracted a considerable amount of attention within recent years. When induction motors first came into general use, their advantages were so obvious and so highly appreciated that their most serious disadvantage—that of a low power factor—seems to have been almost overlooked. Closer acquaintance with this type of motor soon made it evident, however, that its usefulness could be greatly increased if some means of improving the power factor were devised. The work of Leblanc, Scherbius, Miles Walker and Kapp in this connection is well known, and has resulted in a partial solution of a very difficult problem. Another partial solution is to be found in the method which forms the subject of the present paper. The essential difference between these two methods is very clearly brought out in Fig. 1, which shows that if a corrected induction motor (i.e. one fitted with a phase advancer) and an induction motor arranged for synchronous operation are both designed so as to work at a power factor of unity when running on full load, then at lighter loads the corrected motor will take a lagging current, while the synchronous motor will yield a leading current. In this lies the advantage of the latter type of motor. If we compare the behaviour of an ordinary synchronous motor with that of an ordinary induction motor used as a synchronous motor, the most striking difference between the two types under running conditions lies in the fact that the ordinary type of synchronous motor is capable of maintaining a very high power factor over a wide range of load, whereas the ordinary induction-type run synchronously is, as regards power factor, very sensitive to changes of load.* A second point of difference is that whereas the ordinary synchronous motor possesses a large overload capacity, the ordinary induction motor run synchronously has only a very narrow margin of overload. Both these differences result directly from the use of a long air-gap (and consequently a strong field) in the synchronous machine, and a short gap in the induction machine. So far as running characteristics are concerned, therefore, the long-gap machine is to be preferred to the short-gap one. When we come to consider starting characteristics, however, the conditions are reversed: the short-gap machine is much to be preferred to the long-gap one. It is true that a short-gap machine may be given the necessary overload capacity by heavily over-exciting it at full load, and this is the method used in the machines referred to in the paper, but the second disadvantage of the short-gap machine—that of a power factor which varies to a large extent with changes of load—will still remain. It may be argued that this variability of the power factor, so far from being a disadvantage, is a distinct gain, for when the load decreases, the leading component of the current increases (see Fig. 1), and the machine begins to act as a power-factor corrector for other loads on the system which take lagging currents. From this point of view, the author is justified in stating that the long-gap machine is uneconomical. But if we suppose that the present type of induction motor is largely or entirely superseded by the induction-type synchronous motor, then the large leading currents taken by such motors when lightly loaded would be just as troublesome as the lagging currents which are, under present conditions, taken by ordinary induction motors, and we should then welcome any devices which draw a lagging current from the mains. The ideal motor is one having a reasonable overload capacity, capable of running at a high power factor under all loads, and of starting against a heavy load with a reasonably small current. The first two conditions are fulfilled by a long-gap machine, the last by a short-gap one. It would therefore appear that the best all-round results are obtainable only by adopting a compromise between the two types, and that the author's condemnation of the long-gap machine, although justifiable under existing circumstances, cannot be regarded as generally applicable. In the ordinary induction motor, the amount of copper available on the rotor is insufficient to provide any appreciable margin for overloads if the machine is operated synchronously with the rotor used as the field structure; if such margin is desired the normal rating of the machine may have to be considerably reduced. From this it is evident that in order to obtain the best use of materials, the design of the induction-type synchronous motor must proceed on somewhat different lines from those of an ordinary induction motor. Since in general it is easier to find additional copper space on the stator than on the rotor, the use of "inverted" machines, referred to by the author, presents certain advantages, although it could hardly be adopted in the case of machines supplied at high voltages without transformers.

The following arrangements appear to have been tried for the actual construction of the rotor and the method of starting: (1) The rotor is provided with either a three-phase or single-phase winding. It is started in the usual manner as an induction motor through resistances, and when normal speed has been reached the rotor circuit is momentarily opened, and immediately afterwards connected to the exciter circuit. In the case of a three-phase rotor, two phases connected in series may be used, or else one phase in series with the other two connected in parallel. This is the method adopted in the author's machines. (2) The rotor is provided with two windings: a single-phase exciting winding permanently shunted by a suitable resistance (the object of which is to prevent the induction of too high a voltage in the winding), and a three-phase starting winding. The machine is started up in the

* The excitation being supposed to remain constant in each case.

usual way, and when the three-phase starting resistances have been cut out the exciting voltage is applied to the field winding, and the machine falls into synchronism.* The three-phase winding is allowed to remain short-circuited so as to form a damping winding. (3) The rotor has a three-phase winding and the usual three-phase starting resistances. After these have been short-circuited, one of the three phases is short-circuited independently (from neutral point to slip-ring). The exciting voltage is then applied, through a suitable safety resistance, to the short-circuited slip-rings which are connected to the remaining two phases. The slip-ring short-circuit is next opened, thus allowing an exciting current to flow through two phases in series and enabling the machine to pull itself into synchronism, the third phase being allowed to remain on short-circuit to form a damping winding. The safety resistance is next cut out, the exciting current rising to its full value. It is claimed that this method effects a smoother starting than those in which the rotor circuits are momentarily opened prior to the application of the exciting voltage. The following references may be added to the bibliography given in the paper: J. R. Murray, *Electrician*, 1921, vol. 86, p. 561; and A. M. Taylor, *ibid.*, p. 386.

Mr. L. H. A. Carr (*in reply*): Dr. Hay suggests that if the synchronous induction motor entirely replaces the induction motor, leading currents will at some future date become as troublesome as lagging currents are to-day. In view of the large numbers of small motors which are in use and which in any case will be left as

* The current passing through the resistance shunting the field winding is insufficient to increase the excitation loss appreciably.

plain induction motors, this condition is never likely t arise. Dr. Hay's analysis of the long-gap and short-ga types of machines is exceedingly clear, but my experien is that a machine giving a high leading power fact at all loads is not the type required. What is want is a machine giving constant reactive kilovolt-ampere i.e. a constant power-factor-correcting duty, and th condition, which means necessarily a low leading pow factor at small loads, is practically met by the sy chronous induction motor.

Dr. Hay's classification of the methods of starting ma be slightly extended by the addition of a fourth typ where the exciter is permanently connected in circu with either a single-phase, two-phase or three-pha winding. I have already dealt with the disadvantag of this. Dr. Hay's type (1) is the only satisfacto method. The disadvantages of his type (2) are, first, th need for carrying so much idle copper on the rotor, an secondly, the higher magnetic leakage necessitated b this construction. The disadvantage of his type (3) that it is not certain that the machine will synchroni when the reduced exciting current is first switche into the secondary circuit. If the exciting current not sufficient to synchronize the machine, an oscillatio is set up in the line which will persist until the excitin current is large enough to cause the machine to pu into step. The only way to avoid this disturbance to leave the exciter disconnected until the machine h reached full induction-motor speed, and then switch o full exciting current, sufficient to synchronize th machine in a single cycle of slip. This appears t reduce the disturbance to a matter of 4 or 5 cycl of supply.

THE DETERMINATION OF THE DECREMENT OF A DISTANT STATION BY MEANS OF A COIL AERIAL.

By Major J. Erskine-Murray, D.Sc., Member, and B. Williams, B.Sc.

(*Paper received 28th December, 1921, and read before the* Wireless Section *1st February, 1922.*)

Summary.

The paper describes a method of measuring the decrement of a distant transmitting station, which is based on the fact that if a coil aerial be in a plane 45° off the bearing of the station, the current induced in it is $1/\sqrt{2}$ of that when on the bearing. This relation is used to get the value of the capacity which will give half the square of the current and hence give the decrement by Brandes's method directly from the values of the capacities.

(A) General Theory.

The determination depends on the equalization of received currents without measurement of their absolute values.

If a loop is placed with the plane of its winding pointing in the direction of a transmitting station the electromotive force induced in it is a maximum. If the loop is inclined at an angle θ to this direction (hereafter called the bearing) the induced E.M.F. is proportionate to $E_{max.} \cos\theta$. If $\theta = 45°$ then $E_{45°} = E_{max.}/\sqrt{2}$, or if the coil is in resonance with the transmitter $I_{45°} = I_{max.}/\sqrt{2}$.

In the usual method of determining the decrement of a transmitter a receiving circuit consisting of a coil, condenser and thermo-ammeter is coupled to the transmitter, and the two values of the capacity C_1, C_2 are noted at which the current in the circuit is $I_{max.}/\sqrt{2}$, where $I_{max.}$ is the current at resonance.

If d_1 = decrement of transmitter and
d = decrement of apparatus,

then
$$d_1 + d = \pi \frac{C_2 - C_1}{C_2 + C_1} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In the case of the loop aerial (assuming the signal strength to be proportional to the received current) inclined at 45° to the bearing, the signal strength is $1/\sqrt{2}$ times the signal strength when the loop is on the bearing—it being understood that resonance is obtained in both cases. If now the loop on the bearing be detuned on either side of resonance until the signal strength is equal to that obtained with the loop at 45° and in resonance, then the capacity values so obtained may be substituted in Equation (1) and the total decrement of the transmitter and apparatus be determined. The conditions to be fulfilled and the general procedure to follow are therefore :—

(1) Find the bearing by any suitable method.
(2) Set the loop at 45° to bearing and tune accurately. Note the signal strength.
(3) Set the loop on bearing and detune on either side of resonance until signal strength is equal to that obtained in (*b*). Note the capacities C_1 and C_2, and hence determine $d_1 + d$.
(4) Find d (= the decrement of the apparatus) by a continuous-wave method. d_1 is then determinate.

(B) Determination of Total Decrement.

Two possible methods can be adopted, namely : (I) the visual, and (II) the aural.

(I) *Visual method.*—This is the more accurate method and is less complicated than method (II) ; it is, however, applicable only to strong signals of a regular character and where there is no appreciable interference. One coil and one condenser are required. The signals on the bearing are equalized with those

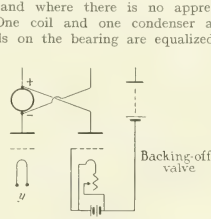


Fig. 1.—Balancing D.C. Component in Anode Circuit.

obtained on the 45° to bearing position, by making them produce equal effects in a recording instrument. Using a 7-valve amplifier across the coil and tuning condenser, the two signals may be said to be equal if they produce the same drop in the anode current of the last valve. This drop may be indicated in two ways :—

(*a*) By inserting a milliammeter in the anode circuit of valve 7.
(*b*) By inserting the primary of a transformer, the secondary of which is connected to a crystal (adjusted to its best rectifying point) and a micro-ammeter.

A continuous signal will produce in the first case (*a*) a steady current less than the normal, and in case (*b*) will produce a steady deflection of the micro-ammeter ; there being no current when there are no signals.

In (*a*) a change of current from about 2 mA to 1·5 mA has to be dealt with, dependent of course on strength of signal. For rough work a milliammeter

reading to 3 mA may be used; for more accurate work, however, the anode current through the indicating instrument should be "backed off," so that a delicate micro-ammeter may be used and a drop of a few micro-amperes noted.

A suitable scheme for "backing off" the anode current is shown in Fig. 1.

The anode current of the "backing off" valve is sent through the indicator in the opposite direction to that of valve 7. The anode current of the "backing off" valve may be regulated by variation of its filament current, grid potential or anode volts. A high-tension and low-tension battery separate from that of the amplifier must be used. This method is as sensitive as method (*b*), but the latter is handier and sufficient for most purposes; (*b*) is also independent of gradual creep in the anode currents of valve 7, a disturbing factor of case (*a*) where a delicate reading instrument is being used. The bearing may be determined by noting two positions of the coil, one on each side of the bearing, at which the same effect is produced in the recording instrument. The general procedure is then followed in using the visual method. Readings must be taken on signals of the same character and preferably on long dashes.

(II) *Aural method.*—In this method the signals on the bearing are made equal to those obtained on the 45° position by comparison in telephones.

This method is not so easy or accurate as the visual method; it can, however, be employed on weak signals and, with good operation, can be used on ordinary routine transmission. It is the only suitable method where there is appreciable interference.

Two coils and two condensers are required, as it is obviously impossible to keep in mind the strength of the signal on the 45° position during the time it takes to turn the loop back on to the bearing. The two coils must be absolutely interchangeable, i.e. they must

(*a*) Have the same inductance and decrement.
(*b*) Have the same area-turns.
(*c*) Be set accurately at 45°.
(*d*) Be provided with a change-over switch which renders one coil dead when the other is in action, thus preventing any mutual induction effect.

Two coils are wound on identical formers and checked for equality of inductance, high-frequency resistance and self-capacity. The coils are rigidly mounted on top of each other with their winding planes at 45°, and the whole system is made capable of rotation about 360°. The coils are connected up through a tuner box consisting of 4 condensers—two rough tuning (R.T.) and two fine tuning (F.T.) and a change-over switch to a 7-valve amplifier as shown in Fig. 2. The change-over switch is of the barrel type designed so that the make of one coil just overlaps the break of the other. By this means (and by placing the switch to interrupt the grid leak) excessive clicking or howling on changing over is avoided. The condensers are calibrated in micro-microfarads against a standard. Particulars of the coils and condensers are given Section (D).

Preliminary checking of the coils.—Using the Labo tory generator described in Section (D), and the vis method, tables have been drawn up for both c showing the relation between the setting of the in degrees and the deflection obtained in the mic

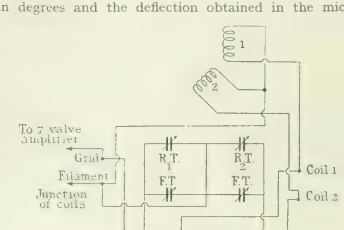


FIG. 2.—Tele-decremeter circuits, first form. In later ty the coil circuits are quite distinct.

ammeter over a complete revolution of the coils. Th tables show:

(*a*) Whether the "pick up" capacity of the c is equal throughout 360° and whether coils are completely interchangeable.
(*b*) The accuracy of 45° setting.

For accurate work to be possible by the aural meth these tables should be identical. If the forego conditions regarding the construction and disposit of the coils are fulfilled it is possible to determine total decrement of the transmitting station and apparatus. It remains to determine the decrement the apparatus.

(C) Determination of the Decrement of the Apparatus.

There are various methods of determining the dec ment of a circuit; of these the easiest of applicat

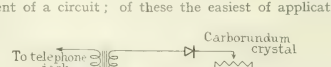


FIG. 3.

is that of determining the resistance of the circu using as excitation continuous waves of the requi wave-length. A description of these methods has b given in Circular of the Bureau of Standards, No. entitled *Radio Instruments and Measurements.*

A large number of tests on the resistance of c have been made by these methods. The therm ammeter employed consisted of a vacuum therm junction and a delicate galvanometer (indicating ty

calibrated against direct current. Its maximum reading was 16 mA and its direct-current resistance (which may also be taken as its high-frequency resistance since the junction only consisted of two short thin wires) was about 9 ohms. Tests were made using a variable non-inductive resistance of from 0 to 40 ohms, and with maximum currents in the circuit of from 16 to 6 mA. Results are consistent within the limits of experimental error if care is taken in exact tuning and in the maintenance of constant value of the induced E.M.F.

When determinations were made of the resistance of a circuit connected up to a 7-valve amplifier of the type used in the previous experiments (no rectification in the first valve) it was found that the resistance (and decrement) of the circuit was considerably altered by switching on the valves. With the valves "on," the resistance also varied when the filament current and potential of the grid of valve 1 were altered. Using the amplifier in its best working conditions for signal strength, determinations of the resistance of the apparatus at various maxima of current in the coil were made. It is, however, possible to use the same method as has been outlined in Section (B). A continuous-wave generator is placed some distance from the apparatus. The same procedure is gone through as for a spark or tonic train station, the capacity values being taken for equal drop in anode current of the first valve—the method being made very sensitive by "backing off" this current in the manner previously described (Fig. 1). The continuous-wave generator is, of course, adjusted to the wave-length of the spark or tonic train station whose decrement is required. This method is to be preferred to the previous one, inasmuch as it measures the decrement under the actual working conditions as to received current at which the set is used.

It is of interest to note that the "backing off" method may be applied to the measurement of high-frequency resistance such as that of an amplifier, by the resistance variation method, if the relation between the drop in anode current and the high-frequency volts applied to the grid of valve 1 is known. A suitable method of obtaining this relation is shown in Fig. 4. S is a continuous-wave generator, in the tuned anode

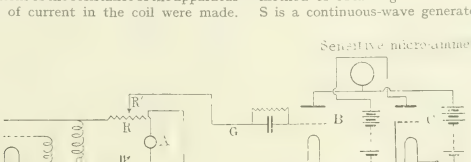


FIG. 4.—Method of Determining Relation between Applied Grid Voltage and Drop in Anode Current.
S, Source of voltage (high frequency); B, Rectifier; C, "Backing off" valve.

It was found that the resistance increased as the maximum current in the coil decreased. It was therefore impossible to say what the resistance of the circuit would be when receiving very small currents. The effect of the amplifier is to impose a leak of varying value (according to the strength of current received) across the condenser. This is equivalent to inserting a resistance in series with the circuit. This effect was checked by substituting for the amplifier a sub-divided megohm and taking observations of the resistance with leaks varying from 1 megohm to 50 000 ohms. Results similar to those obtained when using the amplifier were found. When the resistance across the condenser was infinite or when the valves were off, the resistance of the circuit was constant. In order to ensure that the apparatus has a decrement which remains appreciably the same for different signal strengths the grid circuit of the first valve must be of the order of 2 or 3 megohms. This was effected by interposing a grid leak in the first valve grid circuit. The resistance of the apparatus then remained constant for various maxima of current in the coil.

This method of finding the decrement of the apparatus necessitates the use of a thermo-ammeter which must either always be kept in circuit or else its resistance allowed for in calculating the decrement of the apparatus. circuit of which currents of magnitude from 20 to 100 milli-amperes may be obtained and measured by A at any desired wave-length. R is a constant non-inductive resistance in the anode circuit, a part of which, R', is tapped off and applied to the grid-filament circuit of the rectifying valve.

The applied volts then equal $R'I$, where I is the oscillating current. Owing to the position of A it does not register the d.c. anode current. Curves may then be plotted showing the relation between volts applied to the receiver and drop in anode current. For an average receiving valve with standard grid leak and under normal working conditions, the relation is a linear one for values of applied volts from 0·1 to 1 volt, the relation being of the form

$$D_p = D_0 \sqrt{V} = V_0 K$$

where D_0 = drop in micro-amperes at applied volts $= V_0$; D_p = drop in micro-amperes at applied volts $= V$; K = a constant. An average value of K is 450 μA/$\sqrt{V}$. The resistance of the receiver is therefore calculable. A great advantage of this method is that no additional resistance, such as a thermo-ammeter, is introduced into the circuit of which the resistance is required. A still further application of the "backing off" method to the measurement of high-frequency

resistance in which a knowledge of the relation between the drop in anode current and the applied volts on the grid is not required, is given in Fig. 5.

If R is required resistance of the receiver circuit and R_1 is a known tap of a non-inductive resistance X carrying a high-frequency current I, then the electromotive force applied to the oscillatory circuit consisting of R_1, L, R', C, is $E = R_1 I$. At resonance the current in the oscillatory circuit $= R_1 I/(R + R' + R_1)$.

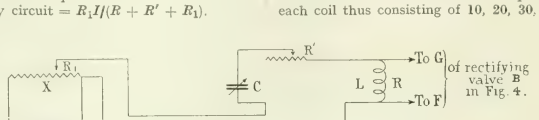


FIG. 5.—Equal Deflection Method for Measurement of High-frequency Resistance.

If $R' = 0$ then $I_1 = R_1 I/(R + R_1)$.
When R' is introduced

$$I_2 = R_1 I/(R + R_1 + R')$$

Suppose that I_2 is made equal to I_1 by increasing R_1 to R_2. Then

$$I_2 = I_1 = R_2 I/(R + R_2 + R')$$

But $I_1 = R_1 I/(R + R_1)$, therefore

$$R_1/(R + R_1) = R_2/(R + R_2 + R'). \quad \text{Whence}$$

$$R = R_1 R'/(R_2 - R_1)$$

Since R_1, R_2, R' are known, R is determinate. The condition $I_1 = I_2$ is fulfilled when the drop in anode

(D) DETAILS OF APPARATUS.

(*a*) *Coils.*—The coils are wound on two exactl similar formers 76 × 38 cm mounted at 45°. Th winding of each coil consists of two sections symmetric about a vertical plane through the axis of rotatio Each section may consist of 5, 10, 15, 20, or 25 turn of No. 24 double silk-covered wire spaced 2 mm apar each coil thus consisting of 10, 20, 30, 40 or 50 turn

The coils when tested gave the following inductance

Tapping	Turns	Coil No. 1 (Bearing)	Coil No. 2 (45° to Bearing)
		Microhenrys	Microhenrys
5	50	2 432	2 423
4	40	1 676	1 670
3	30	1 027	1 024
2	20	508	508
1	10	150	150

(*b*) *Condensers.*—An accurate knowledge is require of the condenser values in micro-microfarads. Th were calibrated against a Sullivan standard by t

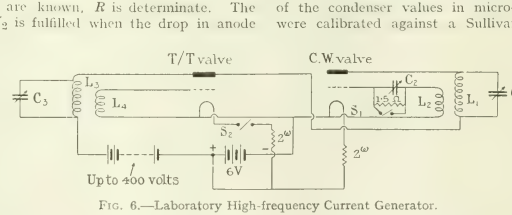


FIG. 6.—Laboratory High-frequency Current Generator.

current of the rectifying valves is the same for both values R_1 and R_2.

This method requires that with $R_1 = 0$ there shall be no drop in anode current, i.e. there must be no inductive or capacity effect between the continuous-wave generator and the inductance L. This is difficult of attainment as it requires that the leads from the generator to the apparatus under test must be absolutely non-inductive and must possess no capacity. In this method very small currents can be used in the continuous-wave generator and measurements have been made using a service syntonizer in which the anode volts = 6.

click method. The fine tuning condensers gave accurate straight-line law from 20° to 160°, i.e. over t normal working range.

The rough tuning condensers gave a straight-li law correct to 1 per cent over the same range.

Condenser	
No. 1. Rough Tuning.	$C_\theta = 221 + 85\,(\theta - 20)$ $\mu\mu$F
No. 1. Fine Tuning.	$C_\theta = 34 + 2{\cdot}175\,(\theta - 20)$ $\mu\mu$
No. 2. Rough Tuning.	$C_\theta = 258 + 84{\cdot}5\,(\theta - 20)$ $\mu\mu$
No. 2. Fine Tuning.	$C_\theta = 30 + 2{\cdot}175\,(\theta - 20)$ $\mu\mu$

(*c*) *Amplifier.*—This is of the ordinary service 7-val pattern with 3 high-frequency valves, 1 detector val

and 3 low-frequency amplifying valves. The first valve can be made to oscillate by suitable adjustment of its grid potential. The amplifier was modified by placing a standard grid leak in the grid circuit of valve 1.

(*d*) *Attachment for visual method.*—This consisted of a Telefunken carborundum crystal with a very sharp rectifying point, with 0·6 volt applied potential. The transformer was a step-down: primary in amplifier circuit, of 5 000 ohms; secondary, in crystal circuit, 1 500 ohms. The micro-ammeter was a Weston 0–50 or 300, the movement being dead-beat.

(*e*) *Laboratory generator for continuous waves, tonic train and squegger.*—In this (Fig. 6):

L_1 = Anode coil of continuous-wave generator—2 000 microhenrys.

C_1 = Continuous-wave generator condenser up to 0·01 μF, variable to 1 $\mu\mu$F.

L_2 = Reaction coil.

(L_1 and L_2 are coils mounted on rectangular formers and arranged to be rotatable about 360°. They are connected by long flexible leads to the main portion of the apparatus. If desired a thermo-ammeter reading milliamperes and a non-inductive resistance may be inserted for facility in calibrating a rectifying valve.)

C_2 = Squegger condenser across a 1·5 megohm leak,

S_1 = Switch short-circuiting squegger condenser.

L_4 = Reaction coil, L_3 = Anode coil } of low-frequency generating valve for tonic train. The variation of anode volts of the tonic train valve is applied to the continuous-wave generating circuit.

C_3 = Condenser for varying the frequency of the tonic train.

S_2 = Switch cutting out the tonic train valve.

The instrument is calibrated by reference to a standard syntonizer previously calibrated against a multi-vibrator which has been checked against a standard fork.

Calibration of tele-decremeter.—Owing to the difficulty of maintaining the decrement of the apparatus constant [see Section (C)] it was found convenient to have available a source of waves of known decrement as a standard of reference. This was furnished by the tonic train generator. The decrement δ_r of the tonic train generator was measured in two ways—

(*a*) By thermo-ammeter method. The difference D in resistance of circuit when tonic train valve was on and off, gave the decrement as $\delta_r = 0{\cdot}00167 D\lambda/L$.

(*b*) By using the 2-coil "*tele-decremeter*" method as described in this paper coupled to a single rectifying valve with its anode current "backed off." Determinations were made with tonic train and with continuous waves and the difference taken.

Both methods gave the same result. The decrement of the tonic train was measured over the range of wave-lengths for which the tele-decremeter is to be used. To determine the decrement of any transmitting station the procedure is:

(*a*) Find the total decrement as outlined in Section (B). Let it be X.

(*b*) Adjust the tonic train generator to the same wave-length as the transmitting station and determine the total decrement of apparatus and the tonic train. Let this be Y.

The decrement of the transmitter $= X - Y - \delta_r$.

Where an accuracy of 5 per cent only is required, the decrement of the apparatus may be assumed to be that due to the tonic train and the factor δ_r neglected.

In calculating X and Y it has been found advantageous to replace $C_1 + C_2$ by the factor $2\lambda^2/1885^2L$, where λ = wave-length in metres and L = inductance in microhenrys of the tapping used. The reason for this is that C_1 and C_2 involve the capacities of the coils, of the connecting leads to amplifier and of the amplifier itself, which latter is a variable quantity dependent on the conditions. $C_2 - C_1$ is still read off the fine tuning condenser.

The decrement formula thus becomes

$$X = \frac{\pi(C_2 - C_1)}{2\lambda^2}$$
$$(1\,885)^2 L$$

Or for the apparatus described in this paper, if

D = difference in condenser readings in degrees, then $C_2 - C_1 = 2{\cdot}175D$ micro-microfarads and

$$X = 12{\cdot}11DL/\lambda^2$$

Experiments are being made with the tele-decremeter on a number of transmitting stations and also on radio-telephony and telegraphy sets. Observations already made on Paris, 2 600 metres wave, give a decrement of 0·16.

Note.—The tele-decremeter method was invented two years ago in response to a demand by the British Committee on the International Radiotelegraphic Convention for an instrument by which the relative interference caused by various types of radiation such as continuous waves, radio-telephony and spark could be determined. No work was, however, done in the matter at the Instrument Designs Establishment, R.A.F., until recently, when it had become evident that the matter was as important from a Service as from an International point of view.

[The discussion on this paper will be found on page 356.]

DIRECTIONAL TRANSMISSION OF ELECTROMAGNETIC WAVES FOR NAVIGATIONAL PURPOSES.

By Major J. Erskine-Murray, D.Sc., Member, and J. Robinson, Ph.D.

(*Paper received* 17*th January, and read before the* Wireless Section 1*st February,* 1922.)

Summary.

The paper criticizes the differences between directional transmission and reception as used in navigation and describes in particular a number of directional transmission methods which have been developed by the Royal Air Force. These methods include several in which the determination of a bearing depends on the timing of the moment of equality of signals as heard in the receiver, and also include a new class of directional transmitters in which a characteristic of the radiation, such as a particular wave-length, is alloted to each direction in azimuth.

1. Introduction.

The need for a simple and reliable method of determining the position or bearing of aircraft independently of visual observations, which led in 1917 to the invention of the R.A.F. method of directional reception,* has also been the reason for the production of many new methods for directional transmission. Both systems have their advantages, and disadvantages, and until both have been thoroughly tried out their relative spheres of utility can hardly be defined. The present paper is thus a summary of a large amount of work that has been done in the Wireless Research Branch of the Royal Air Force with a view to designing a directional radio-beacon, the indications of which should be simple and properly suited to the somewhat difficult conditions of aircraft navigation over sea, in clouds, or by night. If suitable for these conditions it will, *a fortiori*, be suitable for use in the easier circumstances prevailing on board ship. A properly designed beacon station for directional transmission should be of equal utility for aircraft and ships; it must therefore be possible to obtain a bearing in a fraction of a minute.

2. Differences between Directional Reception and Transmission in Radio-navigation.

The differences between directional reception and transmission may be put into two classes, namely, (i) instrumental differences; and (ii) differences in accuracy and reliability and in the type of errors to which they are subject: a comparison of these will make the spheres of utility of the two methods clear.

(i) In directional reception special apparatus is carried by the craft by means of which the bearing of any ordinary transmitting station within range can be obtained. On the other hand, the determination of the bearing of a directional transmitter can be made either, as in some of the new methods described below, with the ordinary wireless receiving gear alone, or, as in others, with only the addition of a stop-watch or some equally simple accessory. The entire directional part of the system is in the transmitter. Thus where the aerial traffic is large the erection of directional transmission beacons will be justified, but where only occasional it will be more economical to fit aircraft with directional reception. Further, more skill is required for directional reception than for the observations necessary to determine a bearing by directional transmission.

(ii) So far, the results obtained with directional transmission systems recently tried in the R.A.F. indicate that there is a prospect of obtaining as great an accuracy of observation as with the receptional systems. The latter have been more fully developed and are at the moment somewhat more accurate, but, given the same amount of experience, transmissional methods would appear to be susceptible of similar refinements. As these methods are intended for aircraft use the observation is usually made on the equality in strength of signals and not by the direct determination of a minimum.

3. Types of Errors in Directional Reception and Transmission Methods.

In the receptional methods for determining the direction of ordinary transmitting stations certain errors may appear which are variable and which depend on factors external to the instruments. Thus observed bearings are subject to variations which are more pronounced by night than by day. The reasons for such variations are as follows:—

(1) The usual methods of direction finding depend on the assumption that the electromagnetic waves travel with the electric vector vertical and the magnetic vector horizontal, and in consequence the directional apparatus has an axis of rotation which is vertical. If the magnetic vector is not horizontal, there will be errors of observation when using such a system.

(2) Another factor on which accurate observation of direction from ordinary transmitting stations depends, is that the waves should be simple plane waves. It is known, however, that in many cases the waves are not simple but that reflection or refraction occurs in the atmosphere * thus causing a complex wave to arrive at the receiving station. The receiving apparatus does not resolve these various influences, but gives a

* "Wireless in the R.A.F.," *Journal I.E.E.*, 1921, vol. 59, p. 693; and *Radio Review*, 1920, vol. 1, p. 213.

* J. Erskine-Murray: *Proceedings of the Wireless Society, Wireless World*, 1920, vol. 7, p. 651.

result depending on the relative intensities, directions of propagation, orientation of the vectors and phases of the various components, which may or may not coincide with the true bearing.

In the case of directional transmission, on the contrary, orientation of the electric and magnetic vectors has no direct influence on the accuracy of bearing, assuming that the waves are simple; it will have an influence on the strength of signals depending on the type of the receiving aerial, as this may be more efficient for waves with the electric vector vertical, or vice versa. Atmospheric distortion, however, will affect the result. The relative intensities and direction of propagation of the various components will obviously cause errors. The influence of the phase difference may tend to prevent the formation of any zero, or, on the other hand, it may produce zeros in wrong places.

4. Types of Directional Transmitter.

The first experiments on directional transmission of comparatively long waves were probably those initiated by one of the authors at the Marconi station at the Haven, Poole, early in 1899. In these, two vertical aerials were used and the radiation curve predicted was of the figure-of-eight type. Hertz, of course, had shown previously that short waves could be directed by means of a parabolic mirror. Further, and much more exhaustive, work has been done since by Artom, Braun, Marconi, Bellini, Franklin and many others, but descriptions of their methods need not be given here as they are available in other publications. One scheme which may be mentioned, on account of the fact that it has been much used in practice, is the Telefunken radial aerial arrangement. In this there are, say, 90 radial aerials erected at equal angles round the transmitter, in which the directional effect of a long, low Marconi aerial is used. Two aerials opposite to each other form an inverted **W**. The method of obtaining the rotation of the directional effect is to use each aerial or each pair of aerials in turn. As these aerials are 4° apart, such a system gives disconnected radiation and, in order to give a more uniform effect, five aerials together were used.

The methods available for giving a directional system capable of rotation are thus as follows:—

(1) A loop aerial which is rotated.
(2) A series of horizontal aerials radiating from a centre, a switch being used to change from one to the other.
(3) A single horizontal aerial which is capable of rotation.
(4) The Bellini-Tosi system of aerials.
(5) Braun's or Bouthillon and Petit's arrangements in which complex radiation curves may be obtained by variation of phases in the aerials.

The aerial system which at once suggested itself as the most practicable on account of the comparative simplicity of the mechanical parts was the Bellini-Tosi. Experiments were made with this system, but the difficulty of obtaining the accuracy required was so great that work on it has been postponed. The phasing of the two aerials, the influences between parts of the aerial system, and between these and the earth, make it difficult to maintain a constant wave-length, and lead to errors in orientation of the waves. The results that were obtained gave a maximum error in orientation of 6°.

A much more direct method for obtaining the directional radiation seems advisable. With regard to the Telefunken system, the fact that the aerials are separated by 4° introduces discontinuities which are objectionable. The rotation of a single horizontal aerial introduces mechanical difficulties besides making it difficult to allow of quick rotation.

The use of rotating loops is limited by the fact that the radiation from loops is much smaller than with open aerials. It would be possible to increase the radiation by increasing the size of the loops, but this leads again to mechanical difficulties. As, however, the resistance of a loop is low and the power radiated rapidly rises with decrease of wave-length, it is probable that the loop will be more useful than would appear from casual consideration.

The directional transmission methods available which can be applied to any of the above aerial systems may be divided into "Timing" and "Special Characteristic" methods. With the exception of (*a*) and (*b*), below, all the types described have been developed recently in the R.A.F.

5. Timing Methods.

(*a*) The first method is one in which the directional beacon radiates waves which are a maximum in one direction and a minimum in another direction. The whole system is made to rotate in a definite period, say 60 seconds. A special signal is sent out when the maximum or the minimum radiation is in some predetermined direction. This special signal should preferably be sent out by an aerial system which radiates equally in all directions. A distant observer will record the interval between the special signal and the instant of his maximum or minimum radiation and thus obtain his bearing from the beacon. Accuracy cannot be obtained by using the maximum signal, and the observer must observe the minimum signal, noting usually the instant when the signal disappears and that at which it appears again, and taking the mean of these two observations as the instant of his minimum. The Bellini-Tosi radiophares erected in France, and the German "B and C" stations are examples of this method.

(*b*) If it were possible to concentrate wireless energy of ordinary wave-lengths into one direction, i.e. into a form of searchlight beam, it would be possible to determine a bearing by the maximum signal. Using very short wave-lengths such a method is possible and has been realized by Round and Franklin, but involves the installation of special receiving aerials and apparatus on ships and aircraft.

(*c*) Instead of using the minimum signal it is possible to use audible signals for purposes of observation, and such a method is very advisable for aircraft purposes and is used in all the new methods described below. One manner of doing this is the reverse of the R.A.F.

receptional system of direction finding. This will be illustrated in the case where rotating loops are used for transmission. Two loops a and a', at right angles to each other (see Fig. 1), are used for transmitting purposes. These loops are joined in series through a reversing switch r, and have also in circuit a tuning condenser t and the secondary coil s of an oscillation transformer. Power is led to the aerial system through the coupling system sp. The aerial system a, a', is made to rotate at a uniform rate, say 60 seconds per complete rotation, and the reversing switch continuously operated, say two to four times per second. A distant observer will hear a series of signals which will usually be in the order: loud, quiet, loud, quiet. However, when either of the aerials a or a' is pointing towards him the successive signals will be of equal intensity. This instant of equality of signals is what he requires for observation purposes. A special signal will be required when either of the aerial coils a or a' is in a predetermined direction. This special signal may be made by the aerial coils or by a special equi-radial aerial system. In this case, however, the equi-radial

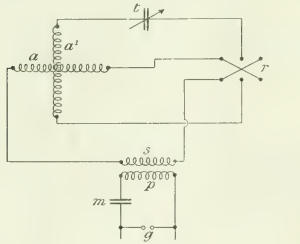


FIG. 1.

system is scarcely necessary, as signals are audible in any case in all directions. To prevent the ambiguity of 90° which is present if the two aerials are of the same dimensions, it is advisable to make one of these aerial coils of larger dimensions than the other. Then there are two instants in the rotation through 180° when the successive signals are equal and it is quite easy to distinguish between them, for one set of equal signals is stronger than the other.

With regard to the rate of reversals, it may be necessary to hear each separate signal. In this case it is not advisable to have more than two signals per second. If the period of complete rotation is 60 seconds, this means that there will be one signal for an angle of 3°.

Attempts to speed up the number of reversals led to the discovery of an interesting phenomenon. When there are 10 to 20 reversals per second a harsh noise is obtained when the successive signals are unequal, but when these are of the same intensity a smooth sound is heard. The change from harsh to smooth effect may be surprisingly sharp. It depends not so much on the duration of each signal, as on the interval between successive signals, and this should be somewhat less than the interval known as the "lag of the ear," which is of the order of 1/40 second. The distinctness of the change depends to a great extent on the type of note used. With rough spark-notes it is not very good, but with purer notes such as those produced by the Wilson interrupter the effect is good. Again, in the case of tonic train where a tuned low-frequency circuit is used, the effect is good. The use of such a method enables observations to be made with almost the same accuracy as with the receptional R.A.F. method. A continuous effect is heard in the telephones, two pure note effects being obtained in 180°; one of these is louder and less sharply distinguished than the other.

The same method may be applied to directional reception methods by speeding up the periods of reversal in the R.A.F. method.

(*d*) Another method which enables signals to be heard continually, makes use of two revolving aerials at right angles radiating waves of slightly different wave-lengths. In the case of continuous waves the difference in wave-length is chosen so small that the waves heterodyne one another and a note is heard in any receiver. If a local heterodyne is added a chord is heard constantly, except when one of the aerial coils is at right angles to the line from the observer. Instead of recording a minimum, the observer listens for the disappearance of the chord. By making the two waves differ only very slightly, instead of a chord being heard in the receiver it can be arranged that a beating note is heard. On small-scale experiments the disappearance of the beat is sharp. It may be noted that although not sharp enough for a good bearing, the maximum on this method is actually much sharper than with a single transmitted wave.

(*e*) The disadvantage of the preceding methods lies in the fact that a considerable time may elapse before a bearing can be obtained. In order to obtain accuracy of observation it is essential to make the period of rotation fairly long, not less than 2 minutes for 360°. For aircraft whose speeds are large, this may be troublesome, for if two or three successive observations are made, as they should be for accuracy, the bearing may have altered very considerably between successive rotations of the directional system.

An automatic timing method has been suggested to make the observations more or less instantaneous. This is a synchronous method, a switch being made to rotate on the receiver synchronously with the rotation of the transmissional beacon. Synchronism is obtained by adjustment to coincidence with a timing signal given in each revolution. This method has obvious difficulties and no experimental work has been carried out up to the present, particularly as a special receiver is required.

6. Special Characteristic Methods.

The object of these methods is to attain the advantages mentioned above, i.e. the abolition of timing methods and the possibility of almost instantaneous observation in certain cases. The principle employed is to radiate waves having some special physical characteristic for every orientation of the transmitting system.

(*a*) These methods differ fundamentally from one which has frequently been suggested, and one which at first sight appears to be somewhat similar, namely, to transmit various Morse signals as the beacon rotates. By employing the equal-signal method as in Fig. 1, the operation is to read the letter on which the pure signal effect is obtained, or on which successive signals are equal. This method, however, has not the advantage of speed.

(*b*) One example of the new method is to vary the wave-length continuously during rotation of the beacon, and here we have the introduction of a new principle in directional transmission, for in this case the physical characteristics of the wave depend on the orientation. Suppose that the form of the aerial is such that the energy is being radiated in the ordinary figure-of-eight diagram. The aerial is rotated carrying its beams of radiation with it; as the bearing changes, however, the wave-length emitted is altered. In this case the arrival of any given portion of the radiation curve, such as the maximum or minimum, at a given bearing, will always take place on a definite wave-length. If the receiver is therefore able to distinguish either a maximum or a minimum, its bearing from the transmitter can be determined by measurement of the wave-length. By recording at the observing station the wave-length of minimum or maximum signal or for any other definite position on the directional curve, the bearing is at once known. Suppose that the beacon transmits waves of 2 000 metres when the minimum radiation is true north or south and the maximum true east or west, and that the wave-length varies continuously down to 1 000 metres as the beacon rotates clockwise through 180°. It is convenient in this case to delete the radiation through the other 180° of the circle in order to prevent confusion. The beacon can rotate very quickly, say once or oftener per second as convenient, or it may be slower than once per second. All that is required of the observer is to measure the wave-length for some particular part of the radiation curve and he at once knows his bearing; for instance, if he determines that the wave-length on which the minimum passes him is 1 500 metres he knows that he is due east or due west of the transmitter.

The method of observation will depend to some extent on whether the type of transmission is spark or continuous wave. The case of spark transmission will be considered with respect to Fig. 2. In Fig. 2 curve *bacab* represents the energy radiated in any particular direction as the beacon rotates through 180°, the wave-length, of course, also varying with the angle. In this case the minimum energy is shown for 0°. The resonance curve in the receiver must be taken into account. Let this be represented by curve *d*. When the wave-length of the receiver is set so that the peak of the resonance curve *d* coincides with the wave-length of the radiation when its minimum is directed towards the receiver, the actual received energy will be in the form of a symmetrical curve *e*, with zero effect at the centre. In case the peak of the resonance curve is displaced as shown by d^x, the received energy will be asymmetrical as shown by e^x. In order to determine the wave-length of minimum radiation it is necessary to adjust the wave-length of the receiver so that a symmetrical effect is heard, i.e. two successive impulses of equal intensity.

In case the received energy is small or the receiver resonance curve so sharp that the signals are inaudible when equal, the system can be used by measuring the wave-lengths at which signals are just audible, the mean of these readings giving the wave-length of minimum radiation, and therefore the direction of the transmitting station.

In the case of continuous-wave radiation, the method of reception used will depend on the range of wave-lengths radiated. If the range of wave-lengths is so small that it will be possible in a heterodyne to hear the heterodyne note throughout, use can be made of a note-tuning device. If the note tuning is good, this

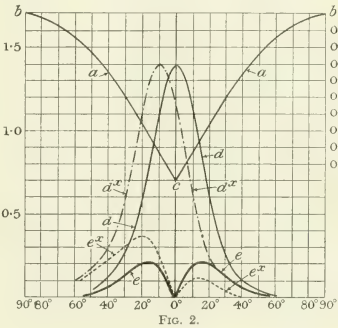


FIG. 2.

particular note will be heard twice during one rotation of the beacon and it is only necessary to adjust the wave-length of the receiver until the intensity of the note is the same on successive occasions. Then the wave-length to which the receiver is tuned is that of the minimum radiation.

For greater ranges of wave-length, should the energy received be so small that nothing can be heard near the minimum, it is only necessary to read the wave-lengths on both sides of the minimum at which the heterodyne swells are just audible and to take the mean. It is advantageous that the variation of wave-length should be uniform with the angular displacement of the beam emitted. For this purpose it has been necessary to design a variable condenser such that when in parallel with the fixed capacities of the oscillating circuit a square-law variation should be given, and thus a uniform variation of wave-length with angle of turning. In the variable-wave system of directional transmission the calculation of the proper form for the movable plates of the condenser may be made as follows:—

(1) It is desirable that the wave-length should change

in proportion to the azimuth angle ; hence, if λ=wave-length, θ = angle, then $d\lambda/d\theta = \text{const.} = (\lambda_2 - \lambda_0)/\pi = K$, say, if the movable plates cover 180 degrees.

(2) Hence $\lambda = K\theta + \gamma$ by integration, where γ is a constant.

(3) But $\lambda = 1\,884\sqrt{(LC)}$ in metres, microhenrys and microfarads ; therefore if the fixed capacity be C_0 and the variable be c

$$\lambda = 1\,884\sqrt{L(c + C_0)}.$$

To determine the constant γ put $\theta = 0$, $c = 0$, then

$$\gamma = 1\,884\sqrt{(LC_0)}$$

Squaring (2) and substituting we get

$$1\,884^2 L(c + C_0) = K^2\theta^2 + 2K\gamma\theta + \gamma^2 ;$$

(4) hence

$$c = \frac{1}{1\,884^2 L}\left(\frac{\lambda_2 - \lambda_0}{\pi}\right)^2\theta^2 + \frac{2}{1\,884}\left(\frac{\lambda_2 - \lambda_0}{\pi}\right)\sqrt{\left(\frac{C_0}{L}\right)}\theta$$

(5) But the area of a curve in polar co-ordinates is

$$\tfrac{1}{2}\int r^2 d\theta$$

(6) Hence the capacity in electrostatic units of a condenser in which n movable plates are used between $n + 1$ fixed plates is approximately

$$(7) \qquad \frac{2n\sigma}{4\pi d}\cdot\tfrac{1}{2}\int r^2 d\theta,$$

or, in microfarads :

$$(8) \qquad \frac{n\sigma}{36\pi d \times 10^5}\int r^2 d\theta$$

Hence to get the equation to the curve of the movable plate from (4)

$$\frac{n\sigma}{36\pi d \times 10^5}\int r^2 d\theta = \frac{1}{1\,884^2 L}\left(\frac{\lambda_2 - \lambda_0}{\pi}\right)^2\theta^2 + \frac{2}{1\,884}\left(\frac{\lambda_2 - \lambda_0}{\pi}\right)\sqrt{\left(\frac{C_0}{L}\right)}\theta$$

Differentiating and simplifying we get

$$r^2 = \frac{5\,980d}{n\sigma}\left\{\left(\frac{\lambda_2 - \lambda_0}{9\,300L}\right)^2\theta + 0{\cdot}638(\lambda_2 - \lambda_0)\sqrt{\left(\frac{C_0}{L}\right)}\right\},$$

where λ is in metres, C_0 in microfarads, L in microhenrys and r and d are expressed in the same but any unit.

It is of course possible to vary other characteristics of the radiation besides the wave-length. If spark or tonic train is used, for instance, the group frequency may be varied as the beam is turned. Tuning would then be acoustical and the determination of direction would be similar to that in which wave-length is varied, except that acoustical frequencies would be dealt with. Other characteristic variations are possible, such as the supersonic variations of the radiated wave-length. It is obvious, therefore, that the field opened up by this principle is a large one. It must be noted that although the wave-length of the radiation from a variable-wave beacon may be varying through quite a large range, it does not jam this range of wave-lengths at all, as the radiation on any given wave-length is only emitted for an infinitesimal fraction of the time of each revolution. No receiving station can therefore hear more than one short click, or at most two, during each revolution of the transmitter, and one or two clicks per second, of course, do not constitute interference which would in any way hinder the reading of other signals ; in fact the transmitter jams *none* of the wave-lengths which it uses.

In addition to the authors the following have been intimately associated with the progress of the work in its various developments :

Wing-Commander G. P. Grenfell, D.S.O. ; Capt. H. L. Crowther ; Mr. T. H. Gill and other members of the staff at the Instrument Designs Establishment.

Discussion before the Wireless Section, 1 February, 1922.

Mr. H. J. Round : With two such interesting papers before us, I find some difficulty in choosing which one to discuss. I have chosen that dealing with the subject of decrements. In the first place I should like to apply a little criticism to the authors' decrement. The term "decrement" refers usually, I believe, to the logarithm of the ratio of two succeeding maxima of current in a wave-train, and that logarithm is only constant when the wave has a logarithmic decrement. On the theoretical basis of a logarithmic decrement in the transmitter, Brandes and others developed an approximate formula, of which that given in the paper is one form, for the determination of the decrement. Such formulæ are accurate over only a narrow percentage of change of wave-length, and are based on the R.M.S. values of the currents obtained in the receiving circuits under different conditions. Suppose such a formula is being used in the old way with a hot-wire ammeter, and the decrement of a wave with a logarithmic decrement is being measured ; a comparison is then made between the R.M.S. values of the current with the receiver in tune and out of tune. The result in this case will be in agreement with the theoretical considerations of the formula, provided the experiment is done accurately enough. If, however, a determination be made in some such way as the authors have done, then it is necessary definitely to ask whether we are measuring R.M.S. current. In the form in which the authors have put their decrometer, both in the visual and aural methods, they introduce rectifying arrangements of some kind. I would agree that if the resulting envelope of the wave-form in the two cases, with the receiver in tune and out of tune, were the same, equality of rectified signals would mean equality of R.M.S. currents. But what basis have we for assuming that the envelope is the same in either case ? We have, in fact, theoretical and practical reasons for believing that the envelopes are different, and consequently equality of signals by no means implies equality of R.M.S. currents, on account of the voltage/power law of the rectifier, which will, incidentally, alter for different rectifiers and different strengths of signal. An extreme example of this is well known in the great

difference in the distance which can be covered by using a plain rectifier as receiver with modulated continuous waves in one case and spark in the other, with equal R.M.S. values of current at the transmitter. It might be said that as we are in practice receiving with rectifiers the result the authors obtain is still useful, but I do not admit this for other reasons as well; in any case, the result is not the decrement. The method can be called a decrescope method and nothing more. In 1908 using methods almost, but not quite, identical with those of the authors, I produced a decrometer which, with modern valves attached, would be equal in all respects to theirs. This instrument is fairly well known as the Marconi decrometer, and was also used as a tele-decrometer. Soon after its issue, I was severely criticized by Dr. Fleming, who pointed out, quite rightly, that I had only provided a decrescope, and he cited the point I have just mentioned, among other reasons. I am rather surprised to see that Major Erskine-Murray has fallen into the same error at this date, or at least, if he has not fallen into it, I am surprised he has not referred to it. I have mentioned how all the formulæ arrived at are obtained on the basis of the logarithmic decrement, and if that which is to be measured cannot be defined as having a constant value of log (I_n/I_{n+1}) then the decrement has no real meaning; only the whole resonance current is of value. What is the meaning of the decrement of a tonic train or wireless telephone measured by such a one-point method? If it had any use I would not mind, but it does not tell us how liable to jam the wave is, because, like a quenched-spark transmitter, it may be sharp at the Brandes position and flat further out, or like a tonic train, where we have really two or three or more sharp waves produced effectively, or like a telephone where the band of wavelengths produced depends on whether a man or a woman is speaking. This type of measurement, I think, at this time in the art is rather futile. I am afraid that my criticism so far has been merely destructive and not as constructive as I should have liked, but with the art changing rapidly at the present time from spark to continuous wave, it would be wiser in my opinion to wait a little, at least, until the spark is completely removed before seriously attacking the problem.

Major H. P. T. Lefroy: In the paper on directional transmission, the authors refer to cyclic variations of the radiated wave-length. In regard to that, I should like to say that in the Army, before the war, we were working on a similar idea, not for direction finding, because we were using a fixed symmetrical aerial, but for a special system of signalling using a periodic variation of wave-length ranging from 700 to 1 800 metres. We conducted some interesting experiments from June 1910 onwards, and got results similar to those described by Major Erskine-Murray, with regard to interference clicks from what I call "transit-flashes." The authors, although they mention 60 periods per minute, have not stated what is the optimum number of periods of wave-length-change per minute which would give minimum flash-jamming on all stations. If the speed is too low the transit-flashes are each so prolonged as to cause jamming; if too fast the flashes repeat themselves so frequently as to become ultimately almost continuous and so again cause jamming. There must be some best periodicity which is neither too slow nor too fast. I think we found that it was about 40 periods per minute for our range of wave-length-variation. I think everyone will agree that in a system of direction-finding in which the bearing found, and therefore the location of the observer, depends on an observed wave-length, it follows that the more selective the receiver is the more accurate will the location be, and therefore it seems from that point of view, with regard both to aircraft and to ships, that observers should be equipped with a very selective receiver. Again, although the transit-clicks of the bearing-indicating signals may not jam the aircraft receiver, or any other receiver, yet the latter receiver may be so jammed by ordinary signals that the operator cannot read the bearing-signals he requires, so that from that point of view also it is therefore desirable to have a very selective receiver. In that connection I should like to suggest that a trial should be made—if it has not already been done—of a supersonic frequency-changer. The authors have referred, on page 351, to supersonic variations of the radiated wave-length; I suggest that great advantage lies in supersonic variations of the received wave-length. This method, with which many are already familiar, gives greatly increased selectivity. I found, trying it on 600 metres, with a continuous-wave heterodyne on 680 metres, that it is excellent for continuous-wave signals, and that the note was not changed for spark signals nor was speech at all mutilated; in fact it was improved by the quieter background. The beat-wavelength in the above case was 5 100 metres; the longer the beat-wavelength used the greater the selectivity; the above length is a good practical one for receiving wave-lengths of from 500 to 1 000 metres. The smaller the decrement of the jamming station is, the better are the results from using such a frequency-changer. It seems to me a very simple and effective way of increasing reception-selectivity, and incidentally it should be easy to use on ships or on aircraft. This leads up to the next point, namely, that by keeping the beat-wavelength constant, as can be done in practice, e.g. at 5 000 metres, it is then possible to gain further the well-known advantages of using a high-frequency tuned amplifier which is fixed in wave-length; and, since the same beat-wavelength could be used by any country or station, this amplifier could be standardized internationally, making it compact, light, simple and cheap, and more stable than a similar amplifier on the shorter wave-lengths actually received on the aerial. Further, I would suggest that a small gap might be left in the scale of wave-length transmissions, by international agreement, so that there would be no risk of direct reception on this beat-wavelength, which otherwise might easily occur.

Wing-Commander J. B. Bowen: With regard to the first paper, and the value of its work to the Service, we are very anxious to know what really does happen in regard to such things as tonic train, and I think there are many of us here who would be interested

to know what really happens in the case of, say, high-speed transmitting stations. I think, therefore, the practical value of the author's work will be very great, and I hope it will be developed. With regard to the direction-finding paper, the authors have mentioned one or two advantages and disadvantages, but I want to enlarge upon one disadvantage, and that is, the question of added weight in carrying special apparatus on any aircraft. The price we have to pay for carrying load on an aeroplane is very heavy, and it is a very serious matter. In designing an aeroplane for production in normal quantities 1 lb. of load may be considered to cost £5 in engine power, lifting surface, etc., and 100 lb. of wireless or other gear will therefore add £500 to the cost of each aeroplane. This is prime cost only. That is not the least important argument for the development of ground direction-finding stations. The authors mention with regard to one system that the period of complete rotation is 2 minutes. I think that is a very serious thing, for this reason. Let us take the case of an aeroplane trying to find its aerodrome in a fog, with a transmitting station on that aerodrome rotating every 2 minutes, and let us assume that the aeroplane is about a mile away, flying in a circle round the aerodrome in the same direction as the beam is rotating. It is obvious that under such circumstances slow rotation is useless, and this seems a strong argument for rotating the beam at higher speeds.

Mr. J. Hollingworth: There are one or two points in connection with the first paper about which I should like to ask a few questions. I think only those of us who have done any measurements of the kind in question know what a tremendous number of pitfalls there are. I have been doing some work on the lines of Major Erskine-Murray, and have had the same experience of difficulties as he has met with, with a certain number of differences, and it is in connection with these that I wish to ask certain questions. Fig. 1 shows a method of balancing the d.c. component in the anode circuit. Is it not easier to do this with a 2-volt cell? The method used by the authors seems to me to mean so much multiplication of apparatus, another 6-volt battery, another valve, and so on. The next point, and the chief point about which I should like information, is this. I gather from page 349 that when working on a spark or tonic-train station, the assumption is made that the effect of the amplifier is the same whether one is working on continuous wave or tonic train; that is, that the decrement of the amplifier is independent of the decrement of the received signal. I am not absolutely certain, but I think that is the point made there; it is, however, one of which I cannot help being rather suspicious. Miller has shown that an amplifier is not so much equivalent to a plain resistance as to a resistance in series with a condenser, and with such a combination and a damped wave we may get rather uncertain effects. So far as regards variation of the decrement of the amplifier, I have been working on the same idea, and I must say I have not found that the decrement of the amplifier varied with the signals. No special precautions were taken to avoid it, and I have been wondering why they got a changing decrement and I did not. A possible explanation is afforded by the authors' statement that there was no rectification in the first valve. This can be read in two senses. With an ordinary high-frequency amplifier, if there is any rectification in the first valve it does not get through, because any low frequency produced in the first valve has a negligible effect on the high-frequency transformer and never gets any further in the amplifier. But there may be just a slight rectification taking place in the first valve, although it does not get any further. If this slight rectification is obtained in a circuit which is equivalent to a variable resistance in series with a condenser, the waves are rather inclined to pile up on the condenser to a value depending upon the decrement. I have been working on the theory of this for some time and have not yet got satisfactory results, but in an ordinary receiver containing a grid condenser and leak the value to which the grid piles up depends on the decrement of the received signals. I see that the authors overcome the effect by putting in a resistance of 2 or 3 megohms. I have not found that necessary, but I must say that I generally found that an amplifier set for maximum signal strength was not in a good position for making measurements; it was liable to be rather unsteady. As a general rule, wherever a measurement has to be made it is better to work with an amplifier less efficient but rather more steady and stable.

Mr. R. L. Smith-Rose: There are one or two remarks I should like to make in connection with the various directional transmitting systems that have been proposed. First of all, in connection with the rotating beacon type, I think Major Erskine-Murray said he still had some affection for this. I am surprised at that, so far as its use in connection with aircraft is concerned, first of all because I think the receiving system which was adopted for use on aircraft was essentially brought out with the idea of avoiding the making of observations on a minimum, and yet that is what has to be done with a rotating beacon: the whole observation is made on the minimum. That is difficult enough on the ground, but it is much more so in the air, with a lot of extraneous noise about. With regard to observation on a minimum, a physiological point, which is not present in the observations of a minimum with the ordinary receiving coil, enters in connection with the rotating beacon; namely, the point at which the signal appears to die away is detected by the ear at a much fainter signal strength than the point at which it is heard to be present again. The point at which the signal is heard to die away is actually much nearer the true minimum than the point at which it is again perceptible. That applies when the minimum has an appreciable interval, which I should imagine is usually the case with a lot of extraneous noise such as takes place on aircraft. With regard to the rotating beacon station, there must be, I think, a rather considerable error due to the antenna or vertical effect. It is noticed, in listening to various types of beacon, that the minimum is not always quite silent. Another disadvantage of the rotating beacon is that it gives practically continuous jamming on the wave-length it occupies. I presume it is necessary

to have several of these beacons for use with aircraft, and more than two of them cannot work on the same wave-length; for if two do work on the same wave-length it would be difficult to locate the minimum position of either. Since an interval of 2 minutes must elapse before it is possible to repeat an observation of the bearing taken on the aircraft, it would seem that the application of the crossed-coil transmitter is hardly suitable. It has the advantage over the minimum system of not operating on zero signal strength, but the disadvantages are that it has a very slow period of rotation—something like 2 minutes—and the accuracy obtainable is intrinsically not very great. From the point of view that a much higher speed of rotation is required, the method last described, in which the wave-length is varied during the rotation, would appear to be much more suitable, and it rather struck me that the actual method of arriving at the correct position at the receiver was somewhat similar both with this method and the crossed-coil system. For its accuracy the system appears to rely on the measurement of wave-length in the receiver, and I should imagine this is not very easy to do in an aeroplane. I was rather surprised at Major Erskine-Murray saying that the system could be applied to give an accuracy of $1\frac{1}{2}$ degrees. From the curve he placed on the screen, showing the wave-length adjustment of that particular receiver, it means he could rely on the wave-length to which the receiver was tuned to 0·4 of 1 per cent. Of course, the receiver circuit may be calibrated on the ground, but that is a rather fine accuracy to expect an ordinary receiver circuit to give; and all kinds of small changes, of which the operator would be unaware, might happen in the machine itself, which would alter it by 1 or 2 per cent and distort the bearing by that amount. I should imagine a trailing aerial was prohibited with aircraft on account of the variation of capacity. There are one or two points I should like to make with regard to errors. It is stated on page 347 that if the magnetic vector is not horizontal there will be errors of observation when using such a system. That is applied, I think, to directional reception. It is generally accepted that the magnetic vector can be in very many positions other than horizontal and still there will be no error obtained with a directional receiver; it can even be vertical and there will still be no error unless two waves, direct and reflected, are present. With regard to night variations, I would suggest that the errors obtained from any type of coil transmitter are likely to be much greater and more frequent than those obtained from ordinary transmitters using directional reception, since there will be not only the vertical polarized wave but also the horizontal, and the refraction effect of the latter will give rise to much greater and more frequent errors than the former. There is one small point which I do not think is quite covered in the paper. There is a system which has been developed in Germany, commonly known as Scheller's course indicator, in which two directional aerials are employed, each transmitting a signal which is the reciprocal of the other, such as A and N. When equal strengths are received the sound heard is a continuous dash. I think some system like that might possibly be useful, if employed with rotating aerials, to determine the point at which the character of the Morse signals is eliminated and so obtain the position of the aircraft relative to the transmitter.

Captain P. P. Eckersley: I suppose that the work on the beacon stations was undertaken more with a view towards its use in war time than in times of peace. For purely commercial work I prefer the use of the method in which the aircraft calls up one or more ground stations for bearings, and is thus guided to its destination. This method has of course a disadvantage in war time because the position of the aircraft is divulged to friends and enemies alike. It has been argued that even for commercial work this method has far from universal application because, for instance, if the aircraft is making trans-oceanic or trans-desert flights, it is impossible to establish the necessary ground stations. I would, however, point out that this difficulty is overcome on regular routes by installing sufficiently powerful installations in the aircraft and on the ground. After all, the position of the R33 during her historical flight across the Atlantic was known hour by hour, and the information was published for all the world to see above the main entrance of Marconi House. It may be again argued that the ground direction-finding method presupposes carrying greater weights on the aircraft, but is this not offset against the fact that the jamming by beacon stations is eliminated? For warlike purposes the aircraft direction finder again would seem to me to score over the beacon station method, first because of its straightforward action, secondly because of the possibility of obtaining a great number of bearings and so a more accurate fix, thirdly because of its absolute secrecy, and last, but far from least, because it minimizes the jamming very largely. The argument that, because the wave-length of the beacon station is constantly varying, the jamming will be less for any given station seems to me to be rather poor. Again, the weight question crops up, but modern installations weigh very little compared with the other weights which must perforce be carried to make the aircraft a useful weapon of attack.

Dr. J. Robinson: Mr. Round in discussing the first paper stated that the instrument described should be called a "decrescope" rather than a "decremeter." No excessive accuracy is claimed by the authors for the instrument. Mr. Round further stated that at the present stage of wireless development much more accurate instruments should be designed. However, the development of such takes time and, as information is urgently required, an instrument as accurate as that described in the present paper is of considerable use.

Professor G. W. O. Howe: One point of interest in regard to the experiment which Major Erskine-Murray has shown in connection with the crossed coil transmitter is the analogy between this and the ordinary flicker photometer. Here we are matching the intensity of two rapidly succeeding sounds; in the flicker photometer two rapidly alternating illuminations have to be matched. As Major Lefroy has pointed out, there is doubtless some optimum speed of operation for

the wireless transmitter, just as there is for the flicker photometer. I must range myself alongside those speakers who have queried what is being measured by means of this decremeter or decrescope, especially when we are listening to or experimenting on a station such as a continuous-wave station which signals by changing the wave-length. If the instructions are carried out, the operator at the distant station is asked to hold down his key. If he does that, it seems to me that the instrument will measure only the decrement of the receiving apparatus itself, but what we want to know in that case is the effective decrement of the station when it is working, not when the key is held down; because, if the key is held down, the decrement is immediately wiped out.

Mr. W. L. McPherson (*communicated*): The methods of measuring decrement presented are of a decidedly neat and ingenious character, eliminating as they do the necessity of having accurately calibrated ammeters of definitely known resistance. The value of the paper might, however, be considerably enhanced if the authors would give some experimental figures to show just what degree of accuracy is readily attainable, and also how they allow for the inevitable earth-capacity effects which are such a bugbear in all high-frequency work. With reference to the backing-off valve circuit as shown in Fig. 1, is it essential to use a valve, or might not an ordinary resistance box serve the purpose equally well? Or has the valve been used as a convenient form of very high resistance for the sake of extra sensitivity? Turning to the visual method, it is very much to be regretted that the authors have described the crystal-to-valve transformer in the usual fallacious method. Surely the correct way to describe such a transformer briefly is to say whether it is of the open core, closed core, or hedgehog type, and give the ratio of transformation (which can easily be measured in a Wheatstone network), together with the impedance of either primary or secondary winding. With this information it is at once possible to say in what kind of circuit the transformer may be efficiently used. So far as I am aware, the practice of quoting the resistance of the windings is based on the mistaken idea that for maximum output the resistance of each winding should be approximately equal to the impedance to which it will be connected. Obviously it is the secondary load impedance which, when transferred to the primary side, should equal the impedance of the supply circuit, and any copper resistance is merely so much waste.

Flight-Lieut. E. F. Turner (*communicated*): It has occurred to me that this form of direction-finding as applied to aircraft may considerably simplify navigation by wireless telegraphy in a manner not specified by the author. If an aircraft is detailed to proceed on a certain course, before leaving the ground the receiver may be set for the wave-length (say, 1 650 metres) which would correspond to the compass bearing from the directional beacon station and would be the wave transmitted by the station when the minimum was passing that particular bearing. The pilot would then fly on his course and the characteristic double signal would be received so long as the course was correct. This would act as a check on the compass fitted in the aircraft, and would eliminate drift. If the characteristic signal were not heard, this would indicate that the aircraft was off the course. The direction in which to turn in order to resume its course would be indicated by the amount the wave-length differed (either plus or minus) from 1 650 metres. This latter would be determined by re-adjustment of the receiver. Provided that a sufficiently selective receiver were used, the need of special apparatus such as rotating or fixed coils would be obviated, and time would be saved in working out the course. Also, an operator skilled in the use of direction-finding coils in addition to the pilot would not be necessary. As regards interference, I consider that the method adopted by commercial aircraft of calling up by radio-telegraphy for bearings, causes far more jamming when used by a number of aircraft at one time, than a variable-wave beacon would. Thus let us take a case where three aircraft require their bearings. The average time taken to give a bearing, i.e. for the aircraft to ask, ground station to acknowledge, aircraft to transmit signals or speech from which the bearing is taken, ground station to plot and transmit bearings, is about 2 minutes. Therefore the last of the three aircraft will not get its bearings for 6 minutes, during which he may have travelled 10 miles. This is of course assuming that the organization is perfect. With the variable-wave direction-finding beacon, any number of aircraft can take their own bearings simultaneously.

Major T. Vincent Smith (*communicated*): Whilst the experiments and systems shown are undoubtedly interesting, it is my strong opinion that there is only one system which should be considered seriously, and that is the directional receiver installed in the machine. The method by which a machine inquires its whereabouts, and is informed by the ground direction-finding stations may work well on a small scale for civil purposes, but only because of good organization. It is at best cumbersome, so for this reason, and because of the information given to the enemy, there is no doubt whatever that the use of such a system would at once cease upon the declaration of war. The same applies to all beacon systems. Lightships, lighthouses, and gas buoys almost disappeared during the war, and no sane authority would provide an enemy with the wireless equivalent. The point I particularly wish to make is that we must use in peace the system we shall use in war, and it is only by its continuous use on civil machines that we shall discover and eliminate all short-comings. The advantages of directional reception in an aeroplane are so obvious that there is no need to labour them. Dr. Robinson's application of this method was one of the technical triumphs of the war, and the magnificent result achieved made us hope for its further development. Nothing finer has ever been accomplished of its kind than the flight made in, I think, August 1918 from Biggin Hill to Paris, and then back by a devious route, under adverse conditions in a Handley-Page machine fitted with Dr. Robinson's apparatus. Major Towler navigated solely by the bearings taken of different commercial wireless stations at home and abroad, and that most practical of all aviators, Major-General Sir Sefton Brancker, who was in charge of the machine, confessed himself completely converted. The commercial success

of aviation must depend upon its regularity and reliability, and I can conceive of nothing more conducive to these than the application of wireless communication for navigational purposes on the principle already successfully put into practice by Dr. Robinson. As it is the only possible system in war, I ask those in authority, therefore, to concentrate their energy upon its perfection in time of peace, remembering that not only its commercial value, but the increased efficiency it would add to the Air Service in time of trouble, will amply justify any money spent upon its development.

Major J. Erskine-Murray (*in reply*): I fear that we have not been quite clear enough in the preliminary statement in the first paper. Mr. Round evidently does not realize that the 45° setting of the coils is only a special case, and that by taking various angles between them from 0° to 90° a complete resonance curve can be obtained and all the information that such a curve can give. This disposes of one of his objections. I agree that further investigation may be required as to the relation between the impressed E.M.F. and the current induced, when an amplifier forms part of the circuit, but it must be borne in mind that only equal currents, induced by E.M.F.'s of the same form and decrement though of different amplitude, are here compared. A correction factor may have to be determined, as has been done by L. W. Austin (*Journal of the Washington Academy of Sciences*, 1918, vol. 8, p. 569), and as indicated in the paper, but this does not invalidate the method. As to what is measured, we do not call it the logarithmic decrement, but simply the decrement; effective decrement, however, might have been better. Few decrements are in fact logarithmic, since a resistance which is constant for different values of high-frequency current is the exception rather than the rule. Thus a definition of some quantity which is a measure of the qualities of all types of waves in regard to interference is certainly required. This has been realized by the International Technical Committee, and, as reported by Prof. Vallauri,* a definition of Effective Decrement has already been laid down. Mr. Round's conclusion is a counsel of perfection, admirable in itself, but of little assistance to those who are struggling to obtain some definite measure of the interference due to the various forms of wave used in radio-telegraphic transmission. Dr. Robinson's remarks are more encouraging.

Major Lefroy has touched on a number of interesting points. I am inclined to agree with him that the optimum rate of revolution of the experimental set shown is about 40 per minute; for other sets, however, it should depend on the total range of wave-lengths covered by the beacon in each revolution, and on the decrement of the receiving station. Minimum jamming would apparently be caused by the beacon which covered the largest range of wave-lengths, for then the clicks would be exceedingly sharp and short, even in ordinary receivers. We have not, so far, worked out the optimum conditions, nor have we tried successive heterodyning; but it is a good suggestion, whether in this connection or in regard to aircraft gear.

* *Radio Review*, 1922, vol. 3, p. 17.

Wing-Commander Bowen's interesting example certainly points to the necessity for a method by which a bearing can be taken in a small fraction of a minute, and indicates that a rapid rate of revolution is preferable.

In reply to Mr. Hollingworth's questions, it would no doubt be possible to use a 2-volt cell in the backing-off measurements, but the method used is convenient and gives a fine adjustment. We have not investigated the possibility that the decrement of the amplifier may vary with that of the incoming signal, and though this does not appear likely it is worth trying out. We do not agree with Mr. Hollingworth's statement that high-frequency current rectified in the first valve will not get through the high-frequency transformers, for it is still a high-frequency current consisting of unidirectional impulses.

I leave Captain Eckersley's views on the utility of ground direction-finding stations to be answered by the operator in charge of the Croydon aerodrome wireless station, perhaps some foggy evening next autumn, when the pilots of eight or ten aircraft are simultaneously shouting for their bearings. He will then realize that in peace as well as war the more practical methods are a direction-finding set on the aeroplane or a directional beacon on the ground.

Mr. Smith-Rose appears to have misunderstood the trend of the paper; all the methods described are rotating beacons, not one of them depends on the determination of a minimum signal, but only on the equalization of two easily audible signals which indicates the azimuth of the revolving beam. It is true, as he says, that a signal dying away can be followed down to a weaker sound than can be picked up after passing through zero, but this phenomenon of course does not affect the equalization of two easily audible sounds. The transmitter shown was merely a model, the wave-length range of which was chosen without regard to the attainment of a degree of accuracy such as could easily be obtained with one designed for actual use. The difficulties Mr. Smith-Rose suggests as regards the determination of the wave-length in an aircraft receiver are exaggerated. I disagree with the suggestion that a true bearing can always be obtained with a coil rotating about a vertical axis even if the magnetic lines are sloping. The fact is that with a coil so mounted a true bearing is never obtained by the minimum method unless either the direction of the magnetic lines, or their direction of motion, is strictly horizontal, and even then it is only a bearing in azimuth and gives no indication of the altitude of the source.

Professor Howe is under a misapprehension as to the condition in which the tele-decremeter is used. The transmitting station is generally beyond the control of the observer, and is merely doing ordinary traffic when the measurement is made.

Mr. McPherson asks some pertinent questions which I should have been glad to answer had I the data, and criticizes quite soundly the bad old way in which the transformer is described.

To Flight-Lieut. Turner's interesting suggestion I would add the converse, namely, that if an aircraft flies

towards the beacon so as to maintain equal clicks in the receiver, without altering the tuning, it will get there.

Major Vincent Smith concludes with an excellent argument for direction-finding in aircraft, and I can assure him that this is not likely to be neglected in civil aviation, but as regards his deduction from the closing of lighthouses during the war I would remind him that non-directive wireless beacons were hard at work in 1918 in this country for the very purpose of providing good signals for aircraft direction-finding, and that in Germany a crude, but useful, type of directional beacon was in operation.

DISCUSSION ON

"TELEPHONE LINE WORK IN THE UNITED STATES." *

North-Western Centre, at Manchester, 10 January, 1922.

Mr. W. J. Medlyn: In some cases we may disagree with American practice, and in others what is good practice in America may be quite unsuitable for this country owing to the different physical conditions, but it is always advantageous to know what other administrations are doing so that we may either copy their good points or gather fresh ideas which may lead to a modification of our own methods. The foundation of any successful business undertaking is based on the financial studies of development schemes and, generally, British arrangements are in agreement with the practice which obtains in America. Reference is made on page 89 to the fact that the cable sheath consists of 99 per cent lead and 1 per cent antimony for underground as well as for aerial lines. We use the same proportions of lead and antimony for our aerial cables because pure lead soon crystallizes on account of the vibration; but pure lead is used for underground work. Can the author say whether antimony alloy has been adopted for underground cables in America with a view to increasing the mechanical strength, or whether this alloy is found to be beneficial in tending to prevent electrolytic troubles? I understand that electrolytic troubles are much more prevalent in America than in this country and, although we are not free from such troubles, it is suggested that our advantage in this respect may be due to the Board of Trade Regulations relating to power supply systems. I gather from the description of Fig. 2 that it is the practice to tee the same pairs out to the terminals on two or more distributing poles, so that when a pair is picked up at one pole the working line is left teed on to the dead ends which are insulated at other poles. Our experience of this method has not been encouraging owing to complications of the cable records and the liability of interruption of working circuits due to workmen inadvertently interfering with the dead ends when making cable changes. It would be interesting to know whether the system has given rise to difficulties in America and, if so, how these difficulties have been overcome. The spacing of poles at from 35 to 50 yards apart, with a maximum of about 37 yards for toll lines, contrasts with our standard spacing of 60 yards, while in towns, owing to buildings and other obstructions, our spans are frequently much longer. The construction cost is, of course, approximately proportionate to the average number of poles per mile, while an increase in the number of wire supports naturally results in an increase in the number of leakage points, thus tending to accentuate insulation troubles. It would be interesting to know whether these short spans are confined to the areas where sleet storms or snow blizzards are prevalent, or whether they are adopted generally in the milder climates. It is stated on page 90 that it is common practice to use plain poles not treated with creosote or other preservative. In a report presented to the Chicago City Council, which was published in *Telephony* in June 1907, a statement made by the engineers of the Chicago Telephone Company showed the life of poles, including the cross-arms, to be 8½ years. Some extensive information relating to the life of poles published by the German Government, and reprinted in the *National Telephone Journal* in June 1911, showed that creosoted poles had a life of about 32 to 35 years. It is difficult to appreciate how any real economy can result from the use of untreated poles with such a short life because, although timber is shown to be cheap in many localities, the labour cost of handling is stated to be high, and when a pole is renewed there is not only the cost of dealing with that particular item, but also considerable extra expense in transferring the wires or cables which it supports. Apart from reconstruction costs, it seems natural also to assume that maintenance charges for short-life plant will also be higher because of the greater liability to breakage in stormy weather. As regards the use of motor transport and machinery, we are glad to give full credit to American engineers, who are working under much more favourable conditions than those which obtain in this country from the standpoint of labour-saving appliances. The comparative costs

* Paper by Mr. E. S. Byng (see pages 85 and 262).

always depend on the balancing point between labour and machinery, an excess of one or the other being uneconomical. We now use motor transport to a considerable extent in this country, although, as the author shows, we are handicapped by higher prices of petrol and vehicles as compared with America. The final test of overall costs is, of course, the price at which we can afford to sell our services to the public, and the evidence brought before the Select Committee on Telephones, recently published, shows that in that respect the British Post Office rates compare not unfavourably with those charged in the United States, when all the factors are fairly taken into account.

Mr. T. E. Herbert : Post Office engineers generally are quite familiar with what is being done in America and elsewhere ; the methods adopted are under constant review and, of course, depend entirely upon the problems that confront the engineer. The slides exhibited by the author show clearly the conditions which have to be met in American telephone practice generally in the matter of construction. These conditions are entirely different from those prevailing in this country. There is an admirable account of American methods in Abbot's " Telephony " which, added to the information contained in the present paper, brings the subject right up to date. I would emphasize the difference in the climatic conditions so far as open-line construction is concerned. After all, the real test which we apply to any system of construction is the annual charges which it involves. The method of development studies outlined by the author does not differ materially from that adopted in this country. Both of them, presumably, consist in forecasting the requirements at various periods as accurately as possible, and then studying the most economical method of supplying those requirements, judged by the annual charges involved. The methods of construction described in Section V of the paper are generally fairly well known, and such methods would in this country lead to disaster. From tests made a good many years ago on various types of expanding stays, one can only describe them as being unequal to the duties required of stays in this country. The use of iron line wire is certainly impracticable in England because its very short life gives a high annual charge. Perhaps the most noteworthy feature in connection with American lines is the adoption of very short spans ; it is probably to this that the overloaded aerial routes in America owe their immunity from destruction. But in this country, even in the wildest parts, the adoption of a short span introduces other features of difficulty. A line was erected at Glossop Moors, a very exposed part, with a span of 20 yards. That line failed in quite a short time because the shortness of the span reduced the dip to something like one-quarter that on a 40-yard span. Considering each wire as a pendulum having a length equal to the dip, the rate of vibration of the wire in the shorter span was 4 times as rapid as in the longer one. The result was that the wire was seriously chafed at the insulators, and when, after 2 or 3 years, huge ice accumulations occurred, many of the wires broke in the short spans. We hope in this country to avoid open routes as much as possible. As regards the use of glass insulators, in 1878 Mr. (later Sir) John Gavey read a paper * before this Institution in which he considered every type of insulator. There is very little that can be usefully added to that paper now. Certainly in this country glass insulators have never found favour. The arrangement by which two wires are terminated in the two grooves of the insulator—for transposition or other purposes—would unquestionably lead to very serious trouble here. It is interesting to note that lately American practice seems to have gone over to the double-shed insulator which, of course, has always been the standard in this country for the reason that we have very much worse climatic conditions. My experience has led me to desire to see the use of aerial cables, even as a temporary expedient, confined to cases where there is no other possible solution of the problem. I believe that at one time the National Telephone Company had the idea that a good method of dealing with a new district was, first of all, to equip it with aerial cables, and later on to lay down an underground system when the requirements were better known. The difference in practice between the two countries would seem to be due to climate, the very long distances traversed in America, and the absence of external interference. The methods of leading-in have been dealt with to some extent by Mr. Medlyn, but I should like to add one or two remarks on that subject. Our experience of vulcanized indiarubber wire has not been altogether happy. Whenever it was necessary to change over from the magneto system to the common-battery system a huge amount of such leading-in wire had to be renewed. It is interesting to note that on an automatic exchange a pressure as high as 600 volts is generated when the receiver is raised. That pressure is not applied to the dielectric of the leaders, because the lightning protector seems to act as a sort of by-pass, since the breakdown voltage of an ordinary lightning protector is of the order of 200 or 300 volts. Certainly such high voltages must have some bad effect on the leading-in. The author states that iron and steel pipes are not used on conduit routes in America. It has been found that in this country the use of steel pipes across bridges, or in other positions where the space is very restricted, has led to very considerable economies, and if the statement made is literally true it would appear that the American methods of construction across small rivers or canals must be exceedingly costly. I was particularly interested in the revival of the modified barrel-organ twist in jointing. It was condemned some years ago owing to the amount of trouble created by it. I notice, however, that in the new method the twist passes through the jointer's fingers, and I should think that after a prolonged period the jointer's fingers become tired, with the result that the new method tends to degenerate into the old one. As regards the speeds of jointing and pulling-in cables generally, I should like the author to say how far they were really practical. Many things are done in a spectacular way to show what is possible, the period or duration of the test being comparatively short. Presumably much of this work is on the lines

* *Journal of the Society of Telegraph Engineers*, 1878, vol. 7, p. 123.

of the Taylor system of scientific management, a paper * on which was recently read before the Institution. I should like the author to say whether a man was permitted to work at the highest possible rate for so long as his endurance lasted in order to make as much money as possible, with resulting danger to health, or whether, as was suggested in the paper I have mentioned, there was any consultation between the engineer and the doctor to ensure that proper periods of rest were allowed so that the man was able to continue his work day after day without injury to himself. The use of mechanical aids is particularly interesting. The problem would appear to be much simpler in America than in this country, since it is obvious that very long lengths of pole line are frequently required. Motor cars and petrol are much cheaper there and labour is correspondingly expensive. Therefore the savings which can be effected by mechanical transport are much less here than in America.

Mr. J. Shea: I am particularly interested in the author's paper, more especially because he has brought home the fact that this country can be too conservative as regards methods of construction. Some years ago Mr. Dane Sinclair (at that time Engineer-in-Chief of the National Telephone Company) and Mr. Frank Gill visited the United States and brought back various ideas and methods, only two of which have stood the test of time, viz. the cable terminal referred to as the No. 14 type, and the wiring ring used for block wiring. I made tests with stranded suspender or messenger wire, but was unable to recommend its adoption, because at that time the suspender strand could only be obtained in comparatively short lengths. It is also very difficult to fit in the clamp when angles exist on the route. Apparently the Americans have got over that difficulty, and perhaps the author can tell us how they keep it in the correct position at an angle when it is being strained up. I notice that the messenger wire is sometimes run on what I consider the wrong side of the pole, i.e. on the outside of the angle. Damage to the cable very often resulted when this was done with the Company's cables, and the practice was forbidden. I have run single steel wire through for as many as 7 spans and it makes quite a good job at a low cost. It certainly is not necessary to terminate the suspender wires at every pole. I am a great believer in aerial cable work, so that I am in direct disagreement with the previous speaker, and agree in principle with the American practice. There is, in my opinion, a distinct field for this class of work in this country, and I should like to see a long length of cable run on a selected trunk route properly strengthened. The National Telephone Company used a good deal of rubber-covered and lead-covered cable, particularly where competition existed, as at Glasgow, Portsmouth, Brighton and other towns, and my experience is that lead-covered cable properly erected is a sound proposition. It is not faultless, neither is an underground system. Vibration which caused cracks in the cable sheath was practically our only trouble, and I do not think that is a problem impossible of solution. There are a few points in American practice which have always puzzled me, and I shall be obliged if the author can give me any information about them. They are as follows: (1) What is the reason for the change in gauge of wire for stranded suspender or stay wire? (page 91). (2) Why are upright bolts or pins used for terminating wires on poles? The heavy wire must surely tend to twist the arm and cause faults by slacking out the wires. Apparently **J** bolts are unknown in America, whereas in this country they are always used when wires are dead-ended. (3) Marline ties (Fig. 12). Do not these have a deleterious effect on the sheath, as was found to be the case in this country? A test made by the Manchester School of Technology clearly proved that anything containing vegetable matter had a distinctly corrosive action on the cable sheath, and the use of marline was forbidden by the Telephone Company. (4) Bonding (page 96). Why is this done, seeing that the poles are not now earth-wired? The American practice formerly was to earth-wire every tenth pole, but this, I note, is not now done, so that any advantage is not apparent to me. In concluding my remarks I should like to refer to drop wiring and to agree with the author as to the high percentage of faults found in the last span, and to say that we have got over this trouble in this district, and we still use open wire in nearly every case.

Mr. G. H. A. Wildgoose: Telephone engineers are always interested in the work of those in America and elsewhere, especially when there is a divergence of practice. At the commencement of the paper the author mentions that about 70 per cent of the telephones of the world are located in the United States, and he later gives the total number of telephone stations as $13\frac{1}{2}$ millions. With the very large experience obtained in installing and maintaining this huge system—perhaps it would be more correct to say number of systems—it would be quite natural to expect their methods to be in advance of ours. It appears to me, however, from the information placed at our disposal that, while the methods do in some cases vary considerably, the underlying principles are substantially the same. Where there is a marked divergence of practice it is due largely to the different conditions existing in the two countries, not merely in a geographical sense but including such matters as the volume of work to be dealt with and the general attitude of the public and the authorities to such undertakings as the telephone system. It has already been pointed out by Mr. Medlyn that development schemes in this country are based upon financial studies. The comparisons of alternative methods of providing plant to serve a given area are based on the annual charges over a period of years. These annual charges include interest on capital expended, in addition to depreciation and maintenance. Other things being equal, the least costly alternative is adopted. The design and installation of underground development schemes in a country where the cities and towns are laid out systematically must be simple as compared with such a country as Great Britain. The irregular lay-out of our British cities and towns, together with the

* "Scientific Management: A Solution of the Capital and Labour Problem," *Journal I.E.E.*, 1920, vol. 58, p. 329.

narrow streets already, in many cases, blocked by other mains, greatly increases the difficulty in serving such localities. The specimen lay-out of cable shown in Fig. 2 would, no doubt, avoid the re-opening of joints so long as the anticipated growth was not exceeded. If, however, the growth in a particular branch were to become abnormal it would apparently be necessary to rearrange the joint. Our experience is that the unexpected frequently happens, and branch routes which to-day give little promise of development may, and frequently do, in two or three years become important telephone areas. The present practice is, however, to provide plant as far in advance of requirements as can be justified on an economic basis and by this means it is expected that the re-opening of joints will be reduced to a negligible quantity. The American practice of making lump-sum payments for private easements would appear to be rather convenient as, in addition to the advantages mentioned in the paper, the consents, presumably, would not contain a 3 months' removal clause. On pages 91 and 92 it is stated that the joint use of poles for telephone and electric supply wire is encouraged and that the advantages are mutual. It would be interesting to know whether the voltage of the supply wires is limited, and whether any trouble has been experienced due to workmen on the pole receiving a shock. I rather think that our linemen would question the advantage of coming into contact with, say, a medium-pressure power circuit while working on the top of a tall pole, and the practice would scarcely seem in accordance with the policy of "Safety First." Perhaps, however, American linemen are not so susceptible to shock as British workmen.

Mr. G. S. Wallace: To anyone who has been closely connected with telephone engineering for the past 30 years, the paper cannot fail to bring into prominence the fact that telephony has so improved as to be quite able to hold its own in the engineering world, although the limit of its powers has by no means been reached. As an engineer more chiefly concerned with exchange plant and subscribers' apparatus, I regret that in the paper there is only a passing allusion to the subject, but the observations on page 109 under "Maintenance" are sufficient to show what is likely to be the practice as regards testing and localizing faults in London and the large provincial areas when the conditions more closely approach those existing in New York than they do at present. The author will doubtless agree that the scheme for the concentration of all testing and localizing apparatus, as adopted in Manhattan, would be found quite unsuitable and uneconomical if adopted in other cities in the United States more closely akin to even the largest English exchanges. We have not yet reached the stage in the provinces when we can accommodate 260 000 telephone stations under one group of test clerks, but when that time does arrive we shall be quite ready to re-model our methods, and not be too proud to utilize American experience in this connection. The principle of telephoning line faults to a central distribution centre has been in operation in Manchester for some years past with very satisfactory results, but under present conditions it is more economical to carry out the preliminary testing at the relevant exchange. The aim of every maintenance engineer is, or should be, to restore service with the least possible delay, but as the number of faults reported each day is a variable factor, depending mainly upon climatic conditions which, in this country, cannot be relied upon for more than a few days, the number of men to be employed on this class of work has to be based upon average figures. I am of opinion that the method of compiling fault statistics, which of course includes durations, now in use in the British Post Office, will compare favourably with that of any other telephone administration in the world. By means of these statistics the Engineer-in-Chief can each month compare the number and duration of all line apparatus and exchange faults in each district throughout the United Kingdom. The Superintending Engineer can do the same as regards each section of his district, and the sectional engineer is in a similar position as regards every exchange in his section. These statistics are also useful for calculating the number of men required for fault maintenance purposes and also for checking any waste or shortage in this direction that might otherwise escape notice. Speed of service and maintenance costs must be in some definite relationship, otherwise the cost to the subscriber will be prohibitive. Whether faults are cleared as quickly in Manchester as in New York depends very largely upon how the New York average of 2 hours per fault is arrived at, and the number of each class of fault included in the calculations. Faults are usually divided into five groups, viz.: (1) Line; (2) Subscribers' apparatus; (3) Exchange; (4) Found correct; and (5) Right when tested. The duration of each of these faults varies very considerably from practically no time in the case of (5) to several hours in the case of long-distance line faults. It will be seen, therefore, that before any useful comparison can be made between American and English fault durations, it is essential that the number and duration of each class of fault should be available, and further information on these points would be useful.

Mr. A. E. White: The rates of progress quoted in the paper, both for cabling and for jointing, are extremely high, and one wonders what were the precise conditions under which these remarkable results were obtained. The speed of jointing is stated to be 150 pairs per hour. I should like to ask the author whether these speeds have been obtained as a result of time and motion studies. It would also add greatly to the value of the paper if the various operations, especially the co-operative team work between the jointer and his mate, could be described in detail. With boiled-out joints there is, of course, a tendency for a film of wax to spread over the bare ends of the copper conductors. I should be glad if the author would say whether in practice this is found to cause any trouble due to high-resistance joints. Recent jointing tests made in this district on a 350-pair 20 lb. unwaxed cable show, in one case, an average speed of 60 pairs for the joint and 99 pairs for the best hour, and, in the second case, an average of 54 pairs per hour and 102 pairs for the best hour. I think these figures tend to show that whilst it may be possible to attain a high speed for

short periods it is not possible to maintain it throughout a working day. If a comparison be made between the costs of jointing in this country and in America, the lower rate of 50 to 60 pairs per hour at a cost of, say, 2s. is to be preferred to the American figures of 150 pairs at a cost of 6s. Not only is the first cost as cheap, but the better workmanship obtained in this country would, I feel sure, be a large factor in the cheapening of the maintenance charges during the life of the plant. The statement on page 100 that a length of 4 miles of standard cable was drawn in from 44 drums by 20 men in one day needs, I think, some amplification. In a recent case the best time for drawing-in one standard length with the aid of a motor winch was 21 minutes, i.e. a rate of 25 ft. per minute. If an allowance of 9 minutes be made for the fixing of the tackle, etc., only two lengths could be drawn in per hour. Can the author say how many winches were in use at the same time and the number of men allocated to each winch ?

Mr. C. E. Morgan: So much has been claimed by and for American telephone engineers that we are apt to discount many of the statements made about their performances, but I think that on the whole there is no need to do so in this case. The author has, no doubt, been shown a good deal of the best-class work, but I expect that he saw little of the worst plant conditions, and the paper therefore does not describe average conditions. It is fully admitted in the paper that the conditions in this country are very different from those in America, but it is nevertheless the duty of every engineer to inquire fully into the respective merits of American and British practice. The differences are chiefly of detail or of policy determined by differences in economic conditions. One of the most striking is the extensive use of aerial cable construction. This is apparently rendered economically possible by the vast stretches of undeveloped territory between telephonic areas such as are practically unknown in this country, and also by the comparatively expensive methods of underground construction in America. There is certainly a scope for aerial cables in this country, but only to a very limited extent, when it may prove to be economical. It is not clear from the paper by what means the cable suspension strand is pulled up to the required tension. Another striking feature of the American practice is the shortness of their aerial spans and the large spacing of 24 inches between the cross-arms. Both these items appear to involve unnecessary expense. On page 93 the use of repeaters on open-wire circuits is referred to. Is any trouble experienced in working such circuits owing to difficulty in maintaining accurate balances ? On page 88 reference is made to the possibility of a cable with a smaller conductor than the $6\frac{1}{2}$-lb. conductor which is extensively used in this country. Such a cable could be justified only in the centre of densely telephoned cities where the duct capacity is of paramount importance. I should like to have further information in regard to the transmission allowances which are worked to in America. Can the author say whether the extended use of repeaters on long-distance circuits in America has enabled the transmission efficiency of the local subscriber's loop to be economically reduced ?

Mr. E. S. Byng's Reply to the Discussions at Newcastle, Liverpool, Leeds and Manchester.

In view of the large number of similar and closely associated questions raised by members at Newcastle, Liverpool, Leeds and Manchester, it will be most convenient to reply to the discussions at those places collectively under the subject headings followed in the paper.

Geographical characteristics.—The effect on telephone lines of climate and the relatively high humidity of the atmosphere in America was referred to in my reply to Sir Andrew Ogilvie (see page 118). The remarks then made apply in some degree to later questions on topographical and other aspects of telephone line construction. It is true that in some parts of the States the highways run for many miles straight through agricultural or prairie land where there are few hills and trees; under such conditions overhead telephone construction work is comparatively easy. In the Eastern States—where most of my time in America was spent—the conditions are, however, much more akin to those which obtain in this country. The roads wind over well-wooded hills and dales, and through a succession of towns and villages. One and the same type of plant is used under these conditions and between cities separated by long open distances; this fact is not generally realized and it serves as a useful corrective to impressions which might otherwise be formulated as to the problems of American telephone engineers. Moreover, winter conditions in the United States present many serious difficulties which are absent in this country—particularly the heavy sleet blizzards which often bring down even the strongest open-wire routes.

Universal service.—The question raised by Mr. Gilpin regarding intercommunication facilities between the various companies is answered by the fact that all the Bell-owned, and many of the Bell connecting stations, are essentially long-distance telephones. The existence of a number of operating companies in various parts of the United States does not concern Bell subscribers, as transmission design provides that each subscriber shall have a nation-wide communication by means of his instrument.

Mr. Kitchen asked whether the long-distance circuits were connected only to specially rented telephones. From the foregoing it will be clear that this is not the case. Since January, 1915, when the transcontinental line (New York–San Francisco) was brought into commercial use, it has been the practice of the associated companies to give universal service on *all* lines. The grade of transmission is determined by engineers of the A.T. & T. Company, the transmission standards being common to all the operating com-

panies. The necessity for the exercise of engineering control by the A.T. & T. Company, to which reference was made by Mr. Kingsbury, is thus demonstrated.

Organization.—Mr. Johnson questioned the desirability of engineers being attached to the staff of the Chief Engineer and also of the General Superintendent of Plant. The functions of the two departments were outlined briefly on page 86. The engineers attached to the Plant Department apply the general principles laid down by the Engineering Department, and develop them in the execution of the actual work. Mr. Gilpin referred to the connection between the Chief Engineer and the Superintendent of Traffic. Policy as to the actual type or system to be followed would, in the first place, probably be suggested by the A.T. & T. Company, but the details would be worked out by the Chief Engineer in conjunction with the Department concerned. Mr. Cowburn was not quite accurate in his comment regarding decisions on technical matters; it was stated in the paper that the Chief Engineer is solely responsible for all such decisions.

The installation of small units of internal plant (a point mentioned by Mr. Whillis), and also of private branch exchanges, is carried out under the direction of the division equipment superintendent. Large units of exchange equipment or extensions thereof are installed by the Western Electric Company's staff.

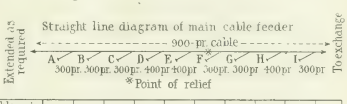
Economics.—In reply to the question raised by Mr. Cowburn regarding cost studies, costs are equated to their values at a common time in order to make a comparison of equal facilities. For example, a cost study to determine whether 300-pair or 200-pair aerial cable should be used would cover at least a period at the end of which 600-pair (the least common multiple of 300 and 200) would be necessary. In addition to the study of these direct costs there is the other point mentioned in the paper, namely, the question of expediency in its relationship to public opinion.

Captain Gaskins inquired whether cable has been laid direct in the ground without any mechanical protection. According to information obtained, the Bell Companies have not adopted this practice; cables are either erected aerially or drawn into some form of duct. It is understood that some of the independent companies in the Western States have laid distribution cables in rural districts without protection, but the practice is not encouraged. Cable so laid is liable to be damaged and, moreover, its scrap value cannot be realized.

Transmission limits.—In reply to Mr. Kitchen and Mr. Morgan, long-distance circuits are designed to furnish transmission (between subscribers) which does not exceed 25–30 miles of standard cable. Local plant is arranged so that transmission losses between any two subscribers' instruments will not exceed 18–22 miles of standard wire. The distribution of the total loss between subscribers' loops and inter-office junctions depends very largely on the circumstances associated with each particular case, but in general it results in the most economical design of local plant. Long-distance circuits are designed to give a transmission equivalent of from 10 to 14 miles of standard cable, while losses in trunk switching are usually kept within three miles of standard cable.

Mr. Cowburn asked about the exchange line limits in America. These are very much the same as in this country. In single-office districts the transmission loss in subscribers' circuits is not in excess of that resulting from the use of 500 ohms of 400-pair 22-gauge (capacity 0·07 μF) in the loop. In a multi-office district, where there are many factors to be taken into consideration, the allowable transmission losses are determined in the fundamental plan.

In reply to Mr. Morgan's question as to the effect of the extended use of repeaters on long-distance circuits on subscribers' loops, the efficiency is not affected by changes in the long-distance circuits, as the most economical transmission standard for a given long-distance trunk is determined and is fixed at a definite value between test boards at the trunk exchanges. In the local areas the transmission efficiency is likewise calculated to give the most economical results both as



Cable pair assignment	A	B	C	D	E	F	G	H	I	
1–101										
102–202										
203–303										
304–404										
405–505										
506–606										
607–707										
708–808										
809–909										

FIG. E.—Typical bridging diagram for stubs on feeder cable.

regards subscribers attached to the same exchange and as regards junction working. The whole system (local, junction, and long-distance transmission) is designed on this principle.

3¼-lb. wire.—The feasibility of using 3¼-lb. wire for a 1 500-pair cable was raised by several speakers. If this practice were adopted in America the higher resistance of the wire would restrict its use to very congested districts (where duct space is at a premium) and to house cables in large buildings, where the number of riser cables would be reduced by the large cable-sheath capacity resulting from the use of the smaller gauge.

Cable sheath.—In reply to Mr. Medlyn, an antimony-alloy sheath has been adopted as standard because it is cheaper, for a given strength, than either a pure lead or tin-alloy sheath.

Lay-out of plant.—In view of the general interest shown regarding stubbing arrangements and feeder cables, a typical bridging diagram is given in Fig. E. The diagram illustrates the overlap of numbers at adjacent stubs and the multiplying of numbering at one or more points for relief purposes. Bridging or

stubbing diagrams are prepared by the plant engineers when the cable schemes are designed; they are required when extensions are contemplated, in order that stubbing arrangements for the additional cable may be planned.

The complications of the lay-out shown in Fig. 2 (to which attention was drawn by Captain Gaskins) may have been somewhat aggravated by an endeavour to show a feeder cable and diminishing cable in the same diagram. Some complexity must be introduced in securing maximum utility; nevertheless the preservation of simplicity is regarded as important. It is not considered good practice to have a large number of idle stubs, but wherever there is a possibility of branch cables being required a short length of stub cable is jointed in at the outset.

Mr. Wildgoose referred to the possibility of an abnormal growth necessitating re-arrangement of the main cable joint. The stub cable is, however, so much larger than is strictly required by the development estimate that there should be no reason for opening the main joint, even though re-arrangement at the stub end may be necessary. As an example, 600-pair stubs are frequently made on 900-pair cable and 900-pair stubs on 1 200-pair cable. Mr. Eames suggests that looping the wires in and out of the main joint via the stub would be preferable to the American method of bridging, but this arrangement would partly defeat the object of the stubbing. The looped wire would be of no value beyond the point at which it was cut and used. When spare, the bridged wire is of value at any stub where it is left, or at any terminal in which it is terminated, particularly for party line service, and in some cases for miscellaneous circuits. The bridging system provides for pole branches and terminals being much larger than may actually be necessary, but it permits of the more costly main feeders being worked to a congestion figure as high as 95 per cent. For this reason the system is considered to be economical.

The suggestion made by Mr. Pratt that the teeing method probably causes a 100 per cent increase in the number of faults is not in accordance with American experience. The ends (known as "cleared ends") are separated and insulated; and by far the greater number of faults occur at some point other than in the main cable system. As Mr. Eames remarked, by opening the stub joint rather than the main cable joint there is a tendency to transfer faults from one point to the other; on the other hand, it must be remembered that the stub is more accessible and is smaller in size, while the wires are of such length that if, through handling, the paper insulation suffers, they can be cut back from time to time.

Mr. Medlyn mentioned the complexity of records involved by the stub arrangement. Cable charts, however, show at a glance where stubbed pairs are terminated; and cable record books show which circuits are in use; therefore the assignment clerk finds no difficulty in deciding which pair can be taken up for a new subscriber's circuit. This explanation partly covers a similar criticism raised by Mr. Adams, but it should also be mentioned that the lowest numbered pairs—in the centre of the cable—are usually the farthest from the exchange.

Treatment of poles.—It was not intended to suggest, in the paper, that the common practice in America was to erect plain untreated poles, as mentioned by Mr. Medlyn. The treatment of pole butts, as described in the paper, is being carried out on a considerable scale for timber obtained locally. In the majority of cases poles do not rot beyond 1 foot above or below the ground-line, and it has been found that in the butt treatment the preservatives penetrates the pole sufficiently to resist the action of rot bacteria or fungus, thus considerably prolonging the life of the pole. A full creosoting process under pressure for locally hewn timber would probably represent a 100 per cent increase on the first cost of the poles, because the freight between the forest and the site of work is not a serious item. In this country where freight charges are considerable, the increase, as mentioned by Mr. Kitchen, is only 20 per cent, and can be justified in all cases.

The life of 8½ years for untreated poles, quoted by Mr. Medlyn, is probably very low as an average figure. Whilst the figure probably varies very widely in different parts of the country, it was understood that in the Eastern States near the coast the life of an untreated pole ranges from 10 to 15 years, while in other districts much longer periods are realized.

Reinforced concrete belt.—The reinforcement of poles by concrete, referred to by Mr. Elliott, is not effected at the time of erection. The process is applied only to poles which show decay and are too short to be reset, and where the cost of complete replacement would be excessive.

Wayleave payments.—In reply to Mr. Kitchen and Mr. Hoole, wayleaves are usually permanent, irrespective of transfer of property. The amounts paid may range from $1.00 upwards, depending upon the conditions. The new owners generally take over the obligations of the old. In practice, any reasonable request for removal is acceded to wherever possible. The franchise for the operation of a telephone system in a town or State usually carries with it certain powers for the erection of poles on highways, and for the cutting of trees which may overhang.

Length of span.—I think the answer to Mr. Kitchen's question, as to whether the greater number of poles used in the States is economically justified, is that winter conditions there are so very severe, particularly in the sleet belt areas, that much more havoc would be caused by storm if longer spans were permitted. In the milder climates mentioned by Mr. Medlyn the same approximate pole spacing is adopted, but poles of a smaller diameter can be used. The increased number of poles materially aids the successful transposition of lines, and affords greater immunity from line faults on large revenue-earning circuits.

Cross-arms.—In reply to Mr. Peel, cross-arms are usually made of creosoted yellow pine. Mr. Jones referred to the arms being staggered; if by this it is meant that alternate arms are placed on opposite sides of the same pole, the assumption is not correct. On a straight route, arms are so placed that on

adjacent poles they face in opposite directions, whereas on a curve they are placed on that side of the pole which faces the middle of the curve. At terminating points, or where spans are long, arms are set so that the strain exerted by the wires is against the pole. In every case (unless local conditions specially dictate otherwise) arms are arranged 24 inches apart, and the wires in the span are therefore the same distance apart. American engineers consider that this wide vertical spacing tends to prevent line faults. It also allows the use of their type of transposition bracket. The limitation of the wire-carrying capacity of poles, referred to by Mr. Eames, hardly applies now that heavy open-wire routes are obviated by the use of aerial or underground cable.

Pole steps.—In reply to Mr. Elliott, linemen use body-belts in conjunction with pole climbers when working aloft on poles which are not stepped. On poles carrying one arm, working aloft is not usual for protracted periods. The men are so adept with their climbers that even in construction gangs ladders are not frequently used.

Staying.—Reference to the frequency of staying—a point mentioned by Mr. Jones—was omitted from the paper, as there were so many other considerations to be taken into account. Briefly, however, reinforcing stays are placed at corners, terminating points, and wherever any strain occurs, as in this country. The number and strength of the stays to be employed are calculated by means of a device called the "guy rule." Storm guys usually comprise the anchorage of a pole in four directions, or the provision of side stays in two directions at approximately every 15th pole. They are used for the purpose of strengthening a pole line to the desired factor of safety, and especially to provide against unusual strains resulting from sleet storms.

Stay rods.—Mr. Gibbins and Mr. Herbert raised the question of the stability of the patent type of rod. The type to be adopted for a particular sub-soil is largely decided by the supervisor's knowledge and judgment of local conditions. The anchor is so selected and so set as not to pull up. It is usually tested and "set" by means of small tackle. The "expanding" anchors, and especially the "never-creep" anchor, pull against undisturbed earth; and they very rarely pull out, otherwise they would not be so popular. Mr. Whillis referred to the unsuitability of boring tools in places where the ground is otherwise than soft, but I believe that there is little difference in the formation of the sub-soil in the two countries so far as the excavation of pole or stay holes is concerned, except perhaps that immediately below the surface more rock may be encountered in many parts of America. Earth-boring tools are then useless and resource must be had to blasting.

Stay wire.—Mr. Shea inquired why there is a change in the gauge of wire employed for stay wire and suspension strand. American engineers prefer to use a strand composed of seven wires, apparently on account of the good lay up which the number 7 secures. In order to obtain a satisfactory range of strands, various gauges of wire are employed in preference to retaining the same gauge of wire with a corresponding diminution in the number.

In reply to Mr. Morton regarding the termination of stay wires at the ground end, it is stated in the paper that one or more 3-bolt clamps are used in a similar manner to that employed in the termination of suspension strand. They are fixed very quickly. Mr. Elliott will perhaps be interested to know that American engineers so seldom find it necessary to tighten up stays that they prefer to avoid the use of swivels altogether.

Wood pins.—In reply to Mr. Elliott and Mr. Morton, steel bolts are used by the Western Union and Postal Telegraph Companies in America, but it is found that they have a tendency to bend. Locust, or osage orange, pins are cheaper; and in spite of occasional breakages (which are not particularly troublesome) they are considered to be very durable. To effect replacement, the nail is withdrawn and the pin driven out from below. The stability of the wooden pin and the shortness of span prevent the tendency of the straight bolt to cant (a drawback referred to by Mr. Shea) becoming a feature of material consequence.

Glass insulators.—Several questions were raised regarding the extensive use made of glass insulators in America. Glass was adopted owing to its cheapness and its satisfactory performance in the special form used. The glaze is of a permanent character and chipping does not—as with the more expensive porcelain—materially affect the insulating properties. Mr. Morton mentioned that glass insulators are rendered unreliable owing to variations of temperature. Whilst the temperature in the States may vary between wide limits during the course of 24 hours, experience has not shown that trouble results from disruptive stresses as suggested. Mr. Jones referred to the conversion of double-shed porcelain insulators into single-shed insulators on account of the insect life which harbours within the darkness of the sheds. Glass insulators do not provide a similar refuge, but as that was not the chief reason which led to the general adoption of glass, it was not mentioned. I am unable to quote insulation resistance figures as requested by Mr. Adams, but it is understood that even in sections of the country where the humidity is relatively high the insulation resistance of long-distance open-wire lines is sufficiently good to permit of phantom and carrier-current working.

Class of wire.—Mr. Baldwin is correct in the assumption that 435-lb. hard-drawn copper is the heaviest wire used on long-distance lines, e.g. this size of wire is used throughout on the New York–San Francisco line, which is 3400 miles in length. This is made practicable by the installation of 12 repeater stations en route. The question raised by Mr. Eames and Captain Gaskins regarding bronze wire has been replied to in the London discussion (page 118).

Joint use.—Several references were made to the joint use of poles, but are for the most part covered in the reply to the London discussion (page 119). Captain Gaskins and Mr. Longman, however, asked for information regarding the voltage of power circuits. The maximum figures permitted on joint use poles are given below:—

(1) Constant-potential a.c. circuits, not earthed, up to 5 000 volts between conductors or, with one side or neutral earthed, up to 2 900 volts to earth. In general, the ordinary primary circuits of the electric supply companies do not exceed 2 000 volts between conductors.
(2) Constant-potential d.c. circuits at less than 750 volts to earth. Trolley feeders are usually well below this limit.
(3) Street lighting circuits carrying current not exceeding 7·5 amperes.

Lines working at higher voltages than those stated are considered to be high tension and are carried on separate routes.

Superimposing.—The question asked by Mr. Gilpin and Mr. Adams as to whether superimposing is considered to be entirely satisfactory, is virtually answered by the extensive use made in America of superimposed circuits. The first long-distance phantom circuit was used in America as early as 1904; since that time the practice has been extended successfully to practically all the long-distance circuits on the Bell System. Each set of four metallic wires is used to transmit three telephone and eight telegraph messages simultaneously. A high degree of efficiency in open-wire plant is essential at all times, and the maintenance on the long lines is therefore kept at a very high standard. In repeater operation on open-wire circuits, basic networks are used for balancing purposes and have been found to be satisfactory.

Installation of open lines.—By means of the running board, which is the subject of a question by Mr. Eames, as many as 10 wires can be run out simultaneously. The drums of wire are mounted on a truck in two rows of 5, so that the 10 wires can be drawn through a fanning strip at the rear of the truck. The running board is fitted with snap fasteners and the wires are run out over the cross-arms. After passing each pole the wires are spread out into their correct pin positions. No. 6 B.W.G. steel wire or small stranded rope attached to an auto-truck is used to draw the running board along. When the final position is reached, strain-equalizing blocks, pulling blocks, and tackle fitted at the bottom of one of the poles are used to strain the wires to the correct tension, as determined by the oscillation method described in the paper. In country districts, if the poles are short and it is practicable to run wires out along the ground, a wire-raising tool is used to lift the wires into position on the arms.

Suspension.—Mr. Eames referred to two bolts being driven through the pole transversely to hold the cable clamp; in Fig. 8 (*a*), however, one bolt only is shown. Where reinforcing links are fixed as in Fig. 8 (*c*) two 4½-inch galvanized drive screws are used. Answering questions by Mr. Shea and Mr. Morgan, after the clamps have been fixed in position, the suspension strand is run out either by the winch of a motor truck or a team of horses. One method of dealing with the strand as it passes each pole is for a lineman to place it in the clamp. The nuts are so adjusted that the strand will not spring out and that no injury will be occasioned when pulling through. The strand is drawn up to the correct tension by means of block and tackle. The bolts at each clamp are then tightened throughout the full length of the suspension strand.

Mr. Vernier and others referred to the strand being situated on the outside of angles. There are two reasons for this: (1) On routes where there is any possibility of "joint use" the field side of the pole is reserved throughout, thus leaving the road side clear for the electric supply company's plant. A second cable along such a route would be run 12 inches below the first. (2) On a large toll cable, such as the New York–Chicago line, the same relative side of the pole is adopted for the entire distance; for example, if the route is running due west, the first cable would be placed on, say, the south side of every pole, whether this was the inside or outside of an angle. When a second cable is required a clamp would be fixed to the opposite side of the through bolt. The dimensions of the bolt and clamp attached to the side of the pole are such that the cable will normally swing clear of the pole; but where the cable is situated on the outside of an angle pole a rope mat or padding of burlap is placed in position temporarily at the time of installation to produce a clearance which is fairly permanent. When the mat or pad is removed, if there is any possibility of abrasion to the sheath the latter is served with a layer of marline. This practice has so far been found in every way satisfactory.

Cable rings.—Several questions asked regarding the effects of vibration and the suitability of metal rings are answered in my reply to Captain Carter (page 122). The short spacing of the rings tends to prevent indentation of the cable sheath; furthermore, when the rings are once in position there is no possibility of their being broken or displaced. I was interested to hear that small cables suspended by the "Elder" ring, as described by Mr. Vernier, have been in service for so long a period, but I do not like the method by which the cable had to be erected. The American type of suspension for the smaller size of cable is precisely the same as for the heavy size. Rings are obtainable in five sizes, ranging from 1¼ inches to 3½ inches. The 1¼-inch ring is used in conjunction with 2 200-lb. strand for cable not exceeding 50-pair 10-lb. in size, approximately 0·8 inch in diameter.

Erection of cable.—Dealing with Mr. Longman's question, it is not customary to treat the lead sheath of cables in any way as a preventive of corrosion. Presumably Mr. Peel's inquiry refers to my verbal description of one of the photographs, shown on the screen, of the erection of 6 000 feet of cable over a gorge where, owing to difficult transport conditions on a section of the New York–Chicago aerial cable route over the Allegheny Mountains, it was impossible to make deliveries of the drums at the desired points. Specially long hauling rope was obtained and passed through the rings for the entire distance of 6 000 feet to the point where the drums were situated. A 500-ft. length of cable was then pulled through the rings to the position required. In order to pull the second 500 ft. of cable into position the hauling rope was

passed outside the rings for the first 500 ft. and through the rings for the remaining 5 500 ft. The same procedure of passing the rope outside the rings for the sections where the cable had been inserted was adopted until all the 12 lengths were in position. The cable was well lubricated; and from inspection made after erection it was evident that no abrasion of the sheath had occurred.

Marline ties.—Mr. Shea and Mr. Eames suggest that marline may have a deleterious effect on the lead sheath. In America, however, for over 20 years marline has been used in manholes for tying **Y** joints, without any trouble resulting.

Jointing.—Mr. Adams described what are known in America as "Hargis" joints. Possibly there are still some of them in use by the independent companies, but the Bell Companies carry out their jointing as described in the paper.

Bonding.—In reply to Captain Gaskins and Mr. Shea, aerial cable is bonded to the suspension strand at every 10th pole, but the strand is not earthed; in fact, every effort is made to insulate the strand from earth, especially at staying points. Mr. Morton's questions in regard to the insulating joint are covered in my reply to Mr. Bartholomew (page 121).

Cable terminal.—The two principal disadvantages of the No. 14 cable terminal mentioned by Mr. Baldwin—condensation on the porcelain block, and corrosion of the terminals—have also been experienced in America, particularly in places such as Pittsburg, where much soft coal is used. Depreciation is retarded by periodical cleaning, a stiff-bristled brush being utilized to remove dust, cobwebs, and other deposit. Cleanliness is essential to satisfactory insulation and, in order to secure it, carbon tetrachloride or alcohol is used where necessary. From time to time both the design and the materials used in the construction of these terminals have been modified. Intensive life-tests are now in progress on a pattern which, it is hoped, will satisfactorily fulfil every requirement.

Life of plant.—In reply to Captain Gaskins, as most of the improvements associated with the construction of aerial cable routes have been introduced during the last few years, life figures are not yet available. American engineers are, however, quite satisfied with the performance of aerial cables up to the present. Rings of a type inferior to the "Bonita" have been in use for 11 years and have not given trouble.

Renewal of cable.—In reply to Mr. Adams, as the cable rings form an aerial conduit, a cable may be withdrawn and replaced in a manner not dissimilar to that adopted in an underground conduit system.

Annual costs.—In reply to Mr. Morton and Mr. Holtum, the saving in annual cost effected by the use of aerial cable results from the annual charges being applied to a considerably lower capital cost. It is agreed that the annual charges (per cent) may be more for aerial cable than for underground cable. Nevertheless, the tendency now is for them to approach the same figure, since while there may be more faults on aerial cable, the cost of remedy per fault is less. Another interesting point raised by Mr. Morton regarding the possibility of total breakdown is met by the fact that a minor defect in the plumbing of an aerial cable would probably come to light only in really wet weather and there would be no tendency for the wet to travel any distance; whereas, in the case of underground cable, manholes and ducts are often either temporarily or permanently flooded with sufficient head of water to penetrate a flaw in the sheath and thoroughly soak the cable. So far as actual plumbing is concerned, jointers make as good a wipe on an aerial cable as in a manhole, where indeed the working conditions may not be so convenient.

Underground conduits.—Mr. Whillis, Mr. Bolton, and Mr. Farrand referred to the use of dowel pins. It is a fact that only two dowel pins are used for the alignment of any size of duct between 2-way and 9-way. The use of dowel pins has a tendency to make a line somewhat inflexible, but where a straight line cannot be obtained and a long slow bend has to be negotiated, the ends of the ducts are chamfered on one side and the joints carefully concreted to preserve alignment, dowel pins being omitted.

Mr. Eames suggests that when concrete is used at the top and sides of conduit it is with the object of maintaining the alignment, but I do not believe this to be the case. The reasons for the use of concrete are given in the paper; and opinion in America is that in city work the danger of damage to ducts without concrete is considerable.

Mr. Herbert's inference that iron and steel pipes are not used at all is not strictly in agreement with the statement in the paper (page 98, para. iii). Although steel pipes have sometimes to be used in city work when negotiating obstructions, their use is not encouraged, on account of the risk of injury to the cable by electrolysis. When crossing bridges over canals and rivers, to which reference is made by Mr. Herbert, creosoted wood duct would probably be adopted, notwithstanding the objection to this type of conduit, indicated by Mr. Morton. Investigation and experience have determined the best composition of creosote for the timber used, so that the preservative has no ill effect upon the lead sheath of the cable. I was surprised to find how popular was wood conduit (pump log) in America.

The 1-inch plank referred to by Mr. Bolton would in no circumstances be used as a foundation for multiple-way vitrified conduit. When laying a nest of creosoted wood conduit, if the sub-soil does not afford a good bedding 1½-inch creosoted wood plank is laid to support the ducts. Top protection is provided also by 1½-inch plank.

I am sorry that I am unable to furnish, as requested by Mr. Cowburn, definite information regarding the use of fibre ducts. It is desirable that fibre duct should be laid with 1-inch concrete on all sides; the total cost is not therefore much less than that of multiple-way tile conduit. One claim made for fibre duct is its low weight. Consequently there may be some field for its use in dry locations and where transport conditions are difficult.

Manholes.—In reply to Mr. Farrand, the type of manhole described in the paper is the standard one. Whilst the desired size and shape of manholes cannot

always be secured, the policy in America is, however, to place all main routes in roadways, and the direct route thus obtained permits of the use of manholes more nearly approaching the standard than would be the case if congested footways were followed. Concrete manholes are preferred, and considerable economy is obtained when templates can be used.

Mr. Bolton raised a question, not covered in the paper, regarding the drainage of manholes. During the installation of a duct run, considerable attention is given to the provision of a fall or gradient towards a manhole. Sump holes are provided in the centre of each manhole floor; and in certain cases connection is made to the nearest sewer. Every precaution is taken to secure dry ducts and manholes in order to minimize the risks of chemical corrosion and electrolysis, and to avoid the possibility of damage to cables by freezing.

Cable vault.—Mr. Baldwin has described an interesting method of leading-in cables to large exchanges, but I consider the American system to be better for the following reasons: (1) Cables can be added or withdrawn without removing any portion of the iron structure. (2) Cables do not cross one another in the rack. (3) Flexibility and adaptability are secured, particularly for the large cable vaults which accommodate cables for as many as 30 000–40 000 lines, since the vaults can accommodate so many more cables. (4) Minimum amount of ironwork is required at the outset, racks and hangers being added as required. And (5), the horizontal type of joint is preferable to the vertical type, as it is easier to construct and maintain.

Cable installation.—The questions raised by Mr. Farrand, Mr. Bolton, and Mr. White regarding the speed of cabling have been covered by my reply to the London discussion (pages 120–122). I may mention, however, that in the record performance referred to, cable was drawn in over a total distance of 4 miles and was not made up of several cables drawn in at one position. Actually there were 50 section lengths —six of the drums containing double lengths which had to be cut and sealed. From personal experience I can assert that the high-geared winch driven by the engine of a 3-ton truck as used in America is incomparably superior to the small portable motor winch driven by a small petrol engine as used to some extent in this country.

Mr. Farrand's question regarding the effect upon the sheath is covered by my reply to Captain Hines (page 122). There is, however, an additional feature which should not be overlooked in connection with cable installation. American engineers spare no trouble or expense in obtaining a clear run for a duct route, in order that cabling work may be facilitated.

In reply to Mr. Peel's question about the average rate of progress, if the extent of the work is sufficiently large and there is enough cable available, the average speed, day in and day out, for country conditions would probably be 50 per cent of the maximum cited, but with a smaller gang and for an 8-hour day. As a rule, overtime is not worked. In view of the general interest in this particular feat, it may be mentioned that the records previously achieved varied from 32 to 38 drums in a working day, but I do not know the number of men employed or the number of hours involved in these cases. The slogan adopted by construction gangs is that "a record is made to be broken"; hence the constant desire to improve upon previous achievements. Under city conditions progress would naturally be less rapid than on country work. Mr. Farrand's impression that the saving in time is due solely to the speed of pulling in is incorrect. By far the greatest source of economy is the elimination of dead time between the drawing in of one length of cable and another.

The circular rings formed in the dressing down of the sheath (referred to by Mr. Jones) are resorted to only for an abnormally hard pull or when long sections are encountered. In general, the woven-wire grip is reinforced mid-way by pieces of galvanized iron wire, as explained in the paper. Lubrication of underground cables is usually carried out by hand, but for aerial cables various devices have been tried. Oil is applied to the cable by means of a "potato-bug sprayer," or it is poured on the cable from a watercan and distributed by a brush or a piece of burlap. Alternatively, the cable is passed through a trough containing lubricant. The metal-duct shields inserted under the cable at the mouth of the duct are left permanently in position.

Boiling-out.—Several aspects of the boiling-out of cable joints were dealt with in the reply to Major Brown (page 119). As, however, Mr. Baldwin and Mr. Farrand have also discussed this process, it may be added that although the congestion of streets in many large American cities is as bad as we know it to be in England, it is not allowed to prohibit the use of hot wax. There may perhaps be more congestion in manholes in this country, but if there be sufficient room for the use of braziers or blow lamps there should also be sufficient for boiling-out. By using the right type of kettle and adopting reasonable precautions accidents will rarely occur. In America the fire hazard and the danger of gas explosions have rendered necessary the prohibition of open flames in manholes; apart from any other consideration, American engineers are thereby committed to the boiling-out process for cables in manholes.

In making any comparison between boiling-out and desiccation, as desired by Mr. Adams, there are several factors to be considered. If the ducts into which subscribers' cables are to be drawn are well laid, the manholes suitably designed and constructed, and the plumbing is carried out satisfactorily, I do not know of any reason why desiccators need be used. For long-distance cables, however, in addition to the boiling-out, advantage accrues in subjecting the cable to an air pressure test upon completion. The CO_2 system has the advantage of portability and to some extent overcomes the objection to a dual method, mentioned by Mr. Baldwin. In my opinion the case for desiccation as a remedy for low insulation on either subscribers' or long-distance cables is not so good, because re-boiling out at the point affected will usually remove the trouble more quickly and at less cost than

desiccation. With desiccation there is also the possibility of inadvertently introducing damp air into the cable and thus prolonging the work.

Jointing.—Several questions were asked regarding the crank-handle method of jointing which has contributed so much to the high rate of work attained in America. Mr. Baldwin raised an interesting point respecting the absence of cottons. This is an important factor, as in the operation of marking the joint position in the first half twist the paper insulation is also removed—an operation made possible by the waxing process, and the absence of cottons. Marking at an angle of 150° provides a sufficient overlap of paper for combining in the first two turns before the twist is commenced. This provision, however, is not absolutely essential, as waxed paper is not liable to run back. The helper does give the jointer direct assistance in many ways, if local conditions permit; but he does not help in the stripping of the ends, as suggested by Mr. Farrand. Where vehicular traffic is congested, it is a rule that the helper shall be above ground in case of emergency. The efficacy of the American method of making twisted joints is questioned by Mr. Adams, but I am assured that one of the principal advantages of this method of jointing over the finger-twist method is that the end of the "pigtail" is very tightly twisted, while, owing to the use of a $3\frac{1}{2}$-inch cotton sleeve, the actual length of pigtail may be as much as $1\frac{1}{2}$ inches. No trouble arises from the introduction of high resistances in subscribers' loops, but in order to avoid any adverse effect in repeater working, due to slight variation in the resistance of the "a" and "b" wires of trunk circuits, the tips of the twisted joints are soldered.

Mr. Herbert and Mr. White are quite correct in suspecting that motion studies have been made in order to eliminate unnecessary movements. In addition to a high speed of work being attained, all fatigue due to superfluous motions is absent. To a casual observer it might appear that the work was being carried out in a leisurely manner, and there is no doubt that jointing at 100 pairs an hour is, to say the least, no more tiring than, say, at 50 pairs an hour by the finger-twist method where pliers are used. The type of scissors used by jointers was specially designed, the blades being $1\frac{3}{4}$ inches long and the loops sufficiently large to admit the scissors being carried on the third finger throughout the whole of the wiring operations. Jointers are also enabled, by means of the file teeth provided on the back of each blade, to strip the paper insulation rapidly from wires at testing ends. It would be undesirable to attempt to break off the twisted wire as suggested by Captain Gaskins; the pressure should be released in the second stage of the fourth operation (Fig. 24), whereas in breaking off the wire an increase of pressure is involved. A further disadvantage is that the wire would not break off square, leaving a raw edge which might puncture the cotton sleeve and cause contact with adjacent wires.

Testing.—Mr. Elliott asked for further information regarding jointer's test-boards. One advantage of the linen test-board over numbered paper sleeves or tags—and one which I noticed in practice—is realized when connecting aerial to underground cable. Current is placed on the wires required at the exchange and picked up by the jointer at the end of the cable stub in the manhole; and the respective pairs identified are passed in turn through the numbered holes of a linen test-board. A section of cable between the manhole and the aerial cable pole having been previously connected to the terminals in a cross-connecting box, the helper is able to ring the pairs through from the terminal to the manhole. As the jointer picks out each pair he removes the wires of corresponding number from the linen board and permanently joints the two together. The linen test-board is eventually freed and removed, as there is no object in allowing it to remain in the joint. The strips accommodate 51 pairs and are numbered from 1 to 1 200. Leather boards are used only for the purpose of identifying quads in duplex cable from the time the capacity unbalance tests are taken until the construction of the finished joint.

The general answer to Captain Gaskins's question regarding conductivity or cross-talk tests is that they are not made during or on completion of the laying of subscribers' cable. Tests for conductivity or copper resistance of the conductors of these cables are recorded on the factory inspection report, and apparently it is not considered that any further tests are required. As regards cross-talk tests (by which it is presumed Captain Gaskins means the buzzer cross-talk tests), these are covered during the jointing of the cables; the jointers use what is known as "Test Set No. 21*a*," for the detection of disconnections, contacts, crossed pairs, and earths. Such tests are made at least once in every eight lengths when jointing new cable, and more frequently when jointing re-covered cable.

Plumbing.—As blow lamps are not permitted, and complicated plumbing is thereby impracticable, objection would be made to the divided joint mentioned by Captain Gaskins. The largest joint made is enclosed by a 20-inch lead sleeve. Cotton sleeves placed in three neat banks can be more tightly bound in than paper sleeves. The cable paster referred to by Mr. White consists of a gummed strip of paper 2 inches wide.

Transmission tests.—In reply to Mr. Mercer regarding the balancing of long-distance cables, the method of testing adopted in this country was first developed for commercial use in the United States, and the results obtained have now reached the same high standard of efficiency in both countries. It is agreed by telephone engineers in general that the matter is of considerable importance for the successful working of long-distance telephone cables. Mr. Holtum considers the minimum insulation resistance fixed in America to be low, but I think it only right to say that, whilst this is given as a minimum normally, the results obtained in practice are considerably higher.

Bonding underground cables.—I would refer Mr. Gilpin to my mention of insulating joints (page 121). Cables are bonded together in manholes in order to prevent interchange of current through earth between the several cable sheaths. Cables can be equally drained; and, moreover, if one cable fails, the current

through the fault to the sheath finds a continuous metallic return path to the station. If an earth plate were installed under conditions favourable for electrolytic action, it would serve merely as an auxiliary anode, and might eventually be rendered ineffective by electrolytic action.

I agree with Mr. Medlyn that it is owing to the Government regulation regarding overall rail-drops that greater freedom from electrolytic troubles is enjoyed in this country.

Terminating cable.—Mr. Baldwin inquired whether the terminating cables at exchanges are dry or impregnated. Such cables are delivered dry but, as described in my reply to the London discussion, the ends are boiled out upon opening for jointing and forming. The joint is again boiled out upon completion, but as pressure tests of dry-core cable are not made the joint is not filled in solid.

Direct underground distribution.—The answer to Mr. Jones's question regarding individual wires for underground distribution is in general in the negative. If, owing to some special restrictions, it is necessary to adopt direct underground distribution, the subscriber concerned is asked to pay the initial cost of the conduit installed upon his property. The cable, however, is laid and owned by the telephone company.

Drop wire.—In reply to Mr. Eames, drop wire consists of two No. 17 B. & S. gauge (35 lb.) bronze or tinned copper-steel conductors, each insulated with rubber compound and covered with a cotton braid thoroughly saturated with permanent waterproof compound. The wire is self-supporting by reason of the tensile strength of the conductors. Mr Herbert raised an interesting point regarding the back E.M.F. and its effect upon covered wires, but I did not hear that drop wire in American cities served by automatic exchanges has given any trouble. As bridle wire for leading-in purposes at a subscriber's premises is used only in connection with a block-wiring system, the protection inferred by Mr. Jones is not required. Protectors, consisting of fuses and lightning arresters (carbon and mica) are fitted inside subscribers' premises for the termination of all drop wires in an area exposed to more than 250 volts. Districts are divided into areas classified as "exposed" or "unexposed" according to whether or not there is any possibility of a telephone line coming into contact with electric light or power lines.

Motor transport.—The limited use of motor cycles, referred to by Mr. Elliott, is due partly to their not being so adaptable or flexible as, say, Ford two-seater, box-body cars. Cars and petrol are both much cheaper in America than in this country, and American statistics show that motor cycles are dangerous from an accident and health standpoint. Motor cycles being generally overloaded in use, they cost nearly as much to maintain as a small car and, furthermore, they do not render nearly such reliable service. Especially during the winter season a car is better suited to the requirements of employees who have to cover long distances. The men can work longer, carry more tools and material, and secure better protection with a small car than with a motor cycle. The all-round superiority of the car is illustrated by the fact that one of the associated companies which once had a fleet of 250 motor cycles and combinations has now reduced the number to about 25. The use of motor cycles in connection with construction and maintenance work has been generally curtailed.

In reply to Mr. Elliott, the usual type of ladder carried at the side of construction trucks is 30 ft. in length when extended (16 ft. closed). The longest type is 40 ft. extended (21 ft. closed).

I am glad to have the opportunity of giving some information on the interesting point referred to by Mr. Johnson. The staff of 250 employed in the motor vehicle department of the telephone company mentioned includes all clerical, supply, and overhead help, about 20 chauffeurs and helpers, porters, building maintenance force, watchmen, etc. Periodically a complete overhaul is made of every vehicle, and all are kept in first-class running condition, with the result that from five to seven years' service is obtained from the trucks, and often more from some of the cars. The construction of all special bodies, tools, and pole derricks for trucks, is also undertaken by the same force. There is a supervisor of motor vehicles attached to the plant department of each of the associated companies.

Labour-saving devices.—Several interesting comments have been made about the suitability or otherwise, for this country, of the various labour-saving devices commonly used in the United States. After having seen some of these machines in use in and around the large American cities I cannot but feel that it is only a question of time before they will be adopted to some extent by civil engineers in this and other countries. In Sweden, for instance, there are two excavating machines in daily use in connection with the installation of long stretches of duct; and these are proving in every way satisfactory.

Maintenance.—Time did not permit of examining closely into the detail indicated by Mr. Wallace, and therefore I am unable to supply much of the information referred to by Mr. Elliott and Mr. Cowburn. Although practice differs in various parts of the country, depending upon the extent of the territory, the usual plan, when a fault tests clear of a subscriber's instrument and wiring, is for the lineman to proceed to the cable terminal, replacing if necessary one span of drop wire (on a pole route), or a length of bridle wire (on an external or internal block-wiring system). When a fault is found to occur in the underground system, the subscriber's circuit is changed to a spare pair. Records at the office are marked accordingly; and, if other faults subsequently develop, localization tests are made and steps taken to clear the trouble permanently.

Captain Gaskins is correct about a periodical inspection being made of the outside plant. In addition to a daily examination by section linemen during the course of their work, a thorough inspection is made of pole routes once a year with a view to ascertaining what renewals are necessary. Complete instructions have been prepared for the information of inspectors as to the extent of the deterioration which can be allowed before a pole should be replaced. During such periodical visits any necessary tree-cutting is carried out.

In this manner the actual number of breakdowns and faults is minimized.

Two or three types of test set are used similar to the one described by Mr. Adams, but they are not used for underground cables unless it is possible to place the "finder" in direct contact with the cable sheath. This instrument is of considerable value in locating earths, crosses, and split pairs in aerial cables where the sheath is available throughout.

In reply to Mr. Jones, all American telephone companies have a complete emergency programme which is put into force immediately the necessity arises. Men and stores are brought from all the surrounding districts to the point of damage, much in the same way as in a large city when a fire brigade "district call" is made. Emergency cable and twisted pair wires are used extensively as a temporary measure to restore service without delay.

PROCEEDINGS OF THE INSTITUTION.

672ND ORDINARY MEETING, 1 DECEMBER, 1921.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 17th November, 1921, were taken as read, and were confirmed and signed.

A paper by Messrs. L. J. Steele, Member, and H. Martin, Associate Member, entitled "The Cyc-Arc Process of Automatic Electric Welding" (see page 136), was read and discussed and the meeting terminated at 7.40 p.m.

SPECIAL GENERAL MEETING OF CORPORATE MEMBERS AND ASSOCIATES, 2 DECEMBER, 1921.

(Held in the Institution Lecture Theatre.)

Dr. W. H. Eccles, F.R.S., Vice-President, took the chair at 5 p.m.

The notice convening the meeting having been taken as read, the Chairman moved that the following resolutions passed at the Special General Meeting held on the 17th November, 1921, be confirmed as special resolutions:—

(1) That the Institution be wound up voluntarily and that Sir James Devonshire, K.B.E., of Electric Railway House, Westminster, S.W. 1, and Percy Fitz-Patrick Rowell, of Savoy Place, Victoria Embankment, W.C. 2, be appointed Liquidators for the purposes of such winding up.

(2) That the property of the Institution remaining after the satisfaction of all its debts and liabilities be given or transferred to The Institution of Electrical Engineers incorporated by Royal Charter dated the 15th August, 1921.

The motion was seconded by Captain R. J. Wallis-Jones and carried unanimously.

The meeting then terminated.

17TH MEETING OF THE WIRELESS SECTION, 7 DECEMBER, 1921.

(Held in the Institution Lecture Theatre.)

Professor G. W. O. Howe, D.Sc., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting of the Wireless Section held on the 9th November, 1921, were taken as read and were confirmed and signed.

A paper by Mr. T. L. Eckersley, B.A., B.Sc., entitled "An Investigation of Transmitting Aerial Resistances" was read and discussed and the meeting terminated at 7.45 p.m.

673RD ORDINARY MEETING, 15 DECEMBER, 1921.

(Held in the Institution Lecture Theatre.)

Dr. W. H. Eccles, F.R.S., Vice-President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 1st December, 1921, were taken as read, and were confirmed and signed.

The following lists of donations were taken as read and the thanks of the meeting were accorded to the donors.

Benevolent Fund.—E. J. Baxter, J. H. Bingham, F. W. Brecknell, A. J. N. Kennett, The Liverpool Sub-Centre (per Mr. O. C. Waygood), J. Mitchell, F. Morton, The Post Office Engineering Department (per Sir W. Noble), H. Whittle.

Library.—The Air Ministry (Meteorological Office); The American Welding Society; F. F. P. Bisacre; The Board of Education; The Board of Scientific Societies; The British Electrical Development Association; The British Engineering Standards Association; The British Science Guild; *Electrical Review;* The Government of the Province of Saskatchewan; Prof. A. Gray; B. J. Hall; The Imperial Mineral Resources Bureau; J. B. Kramer; Lloyd's Registry of Shipping; D. S. Munro; The United States Department of Commerce; L. H. Walter.

A paper by Mr. L. H. A. Carr, M.Sc.(Tech.), Member, entitled "Induction-type Synchronous Motors" (see page 165) was read and discussed and the meeting terminated at 7.40 p.m.

IST[H] MEETING OF THE WIRELESS SECTION, 4 JANUARY, 1922.

(Held in the Institution Lecture Theatre.)

Professor G. W. O. Howe, D.Sc., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting of the Wireless Section held on the 7th December, 1921, were taken as read, and were confirmed and signed.

A paper by Lieut.-Col. A. G. T. Cusins, C.M.G., Royal Corps of Signals, entitled "High-speed Wireless Telegraphy" (see page 245) was read and discussed and the meeting terminated at 7.55 p.m.

674TH ORDINARY MEETING, 5 JANUARY, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 15th December, 1921, were taken as read, and were confirmed and signed.

A list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

The President announced that the Council had decided to keep the Library open until 9.30 p.m. on the evenings when Institution Meetings are held, including meetings of the Wireless Section and Informal and Students' Meetings.

Dr. S. P. Smith, Member, then delivered a lecture entitled "Single- and Three-phase Alternating-current Commutator Motors with Series and Shunt Characteristics" (see page 308), and the lecture was followed by a discussion (see page 314).

The meeting terminated at 8.20 p.m.

675TH ORDINARY MEETING, 12 JANUARY, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 5th January, 1922, were taken as read, and were confirmed and signed.

The President announced that the membership of the Institution now exceeded 10 000 members.

The following cinematograph films were then shown :—

(*a*) "Investigations and Tests on High Tension Switchgear." } Taken by Mr. P. Torchio, and exhibited by Dr. C. C. Garrard.

(*b*) "The Audion." } Exhibited by Mr. F. Gill.

(*c*) "The Telephone of To-day." }

The meeting terminated at 7.40 p.m.

PROCEEDINGS AT THE MEETINGS HELD ON THE 21ST, 22ND, AND 23RD FEBRUARY, 1922, IN COMMEMORATION OF THE FIRST ORDINARY MEETING OF THE INSTITUTION (THEN THE SOCIETY OF TELEGRAPH ENGINEERS) ON THE 28TH FEBRUARY, 1872.

The programme of the meetings was as follows :—

Tuesday, 21st February, 1922 (at 3 p.m.) :

Experimental Lecture by Professor J. A. Fleming, M.A., D.Sc., F.R.S., Member, on "Michael Faraday, and the Foundations of Electrical Engineering" (see page 379).

Tuesday, 21st February, 1922 (at 7.30 p.m.) :

Annual Dinner of the Institution at the Hotel Cecil, London (see page 389).

Wednesday, 22nd February, 1922 (3.30 p.m. to 6 p.m.) :

Short discourses on "Reminiscences and Experiences of Electrical Engineering in both its Technical and Legislative Aspects."

SPEAKERS.

Colonel R. E. Crompton, C.B., R.E. (see page 392) ;
and
Mr. S. Evershed (see page 400) ;
Mr. E. Garcke (see page 398) ;
Mr. W. Judd (see page 406) ;
Sir Alexander Kennedy, F.R.S. (see page 395) ;
Sir Oliver Lodge, D.Sc., F.R.S. (see page 397) ;
Mr. A. H. Walton (see page 402).

Wednesday, 22nd February, 1922 (8.30 p.m.) :

Professor Fleming repeated his Lecture of the previous day.

Thursday, 23rd February, 1922 (3.30 p.m. to 6 p.m.) :

Continuation of discourses.

SPEAKERS.

The Hon. Sir C. A. Parsons, K.C.B., F.R.S. (see page 411) ;
and
Mr. Frank Bailey (see page 416) ;
Sir T. O. Callender (see page 420) ;
Dr. S. Z. de Ferranti (see page 413) ;
Mr. W. H. Patchell (see page 424) ;
Mr. J. Swinburne, F.R.S. (see page 422).

Thursday, 23rd February, 1922 (8 p.m.) :

Conclusion of discourses.

SPEAKERS.

Mr. J. E. Kingsbury (see page 428) ;
and
Mr. Ll. B. Atkinson (see page 441) ;
Mr. B. M. Drake (see page 435) ;
Sir William Noble (see page 438) ;
Mr. G. W. Partridge (see page 431) ;
Mr. C. H. Wordingham, C.B.E. (see page 440) ;

In addition, written contributions were received from the following :—

Mr. O. H. Baldwin (see page 444) ;
Mr. G. Balfour, M.P. (see page 446) ;
Sir Charles Bright, F.R.S.E. (see page 448) ;
Mr. R. A. Chattock (see page 451) ;
Mr. H. J. Dowsing (see page 452) ;
Mr. H. Edmunds (see page 453) ;
Sir Keith Elphinstone, K.B.E. (see page 455) ;
Mr. W. B. Esson (see page 456) ;
Sir R. T. Glazebrook, K.C.B., F.R.S. (see page 459) ;
Prof. A. Gray, F.R.S. (see page 463) ;
Mr. F. E. Gripper (see page 465) ;
Mr. K. Hedges (see page 466) ;
Mr. H. Hirst (see page 468) ;
Mr. J. H. Holmes (see page 470) ;
Dr. G. Kapp (see page 473) ;
Sir James Kemnal (see page 474) ;
Dr. A. E. Kennelly (see page 476) ;
Mr. S. Morse (see page 477) ;
Mr. C. Faraday Proctor (see page 479) ;
Mr. H. W. Ravenshaw (see page 480) ;
Dr. A. Russell (see page 482) ;
Mr. H. M. Sayers (see page 483) ;
Mr. A. Siemens (see page 485) ;
Mr. D. Sinclair (see page 488) ;
Mr. G. Sutton (see page 490) ;
Mr. A. A. C. Swinton, F.R.S. (see page 492) ;
Mr. J. C. Vaudrey (see page 495) ;
Mr. Arthur Wright (see page 497).

The pamphlet containing the programme of the Meetings included the following :

A BRIEF CHRONOLOGY OF ELECTRICAL DISCOVERY AND INVENTION.

Date.	*Name.*	*Nature of Discovery, Invention, etc.*
1790	GALVANI.	Effect of electrical discharge on muscles of a frog's leg.
1799	VOLTA.	True cause of Galvani effect, and invention of galvanic battery.
1812	DAVY.	Published an account of the electric arc.
1816	RONALDS.	Carried out successful experiments with his electric telegraph.
1820	OERSTED.	Deflection of magnetic compass needle by electric current.
1820	AMPERE.	Having heard of Oersted's discovery, a week later he presented a paper to the French Académie des Sciences containing a far more complete exposition of that and kindred phenomena. His original memoirs on electromagnetism were published between 1820 and 1828.

Date.	*Name.*	*Nature of Discovery, Invention, etc.*
1825	Sturgeon.	Electromagnet.
1827	Ohm.	Discovered fundamental law of electric flow.
1831	Faraday.	Electromagnetic induction.
1832	Faraday.	First magneto-electric machine and electric motor.
1832	Pixii.	First magneto generator with commutator.
1837	Cook and Wheatstone.	Magnetic needle telegraph patented.
1838	Sturgeon.	Shuttle-wound armature and two-part commutator.
1845	Wheatstone.	Separately excited electro-magnetic machine.
1856	Werner von Siemens.	Shuttle-wound armature.
1858		First Atlantic cable laid (H.M.S. "Agamemnon").
1858	Holmes.	Magneto-electric machine installed at South Foreland lighthouse.
1860	Pacinotti.	Toothed ring winding for armatures (described in an Italian journal but attracted little attention until re-invented in 1870 by Gramme).
1860	Plante.	Magneto-electric machine.
1866	Wilde.	Magneto-electric machine.
1867	Wheatstone. } Siemens. }	Self-exciting dynamo-electric machine.
1870	Kelvin (then Sir W. Thomson).	Successful completion of the siphon recorder (First patent 1867).
1871	Gramme.	First Gramme machine made with closed-coil ring winding (re-invention of Pacinotti ring).
1873	Hefner-Alteneck.	First drum-wound closed coil winding.
1873	Maxwell.	Publication of "A Treatise on Electricity and Magnetism," 2 vols.
1873		Transmission of power from Gramme generator to Gramme motor shown at Venice.
1876	Jablochkoff.	Electric candle. (London Embankment lit by Jablochkoff candles in 1878).
1876	Bell.	Magnetic telephone.
1877	Edison.	Carbon transmitter.
1878	Edison.	First telephone exchange.
1878	Brush.	Production in the U.S.A. of an efficient form of open-coil dynamo and electric arc lamp suitable for working in series. These inventions of Brush and Jablochkoff inaugurated commercial arc lighting.
1878	de Meritens.	Invention of alternator.
1878	Hughes.	Microphone.
1878 to 1879	Edison and Swan.	Glow lamp. (Edison's British master-patent was filed in November 1879.)
1880		Private installation in Lord Armstrong's house at Cragside, Rothbury.
1881		Electrical Exhibition at Paris.
1881		Godalming. First town to be lighted electrically.
1881 to 1896	Kelvin.	About 1842 Lord Kelvin (then William Thomson) began that long career of theoretical and practical discovery and invention in electrical science. The long series of his patents for electric measuring instruments, gauges and meters began in 1881, and continued until 1896. •Electric lamps he touched only as regards improved means of suspension in 1884. Dynamo-electric generators claimed his attention from 1881 to 1884.
1882		Eastbourne Electric Light Co., Ltd. Supply begun.
1882		Hastings and St. Leonards-on-Sea Electric Light Co., Ltd. Supply begun.
1882		Finsbury Technical College opened.
1882		Electrical Exhibition at Crystal Palace.
1882		Edison Electric Light Company, London, formed.
1882	Brain.	Installation of electric pump in coal mine in Gloucestershire.
1883	Hopkinson (J.).	Demonstration of parallel operation of alternators.
1883		Giant's Causeway, Portrush and Bush Valley Electric Railway opened.
1883	Thomson (J. J.).	On the atom.
1883	Blakesley.	Description of harmonic vector diagram for alternating-current circuits.
1884		"Edison effect" in incandescent lamp.
1885		Parsons steam turbo-generator shown at Inventions Exhibition.
1866	Atkinson-Blackburn-Mori.	First electric coal-cutter installed at a colliery in Yorkshire.
1886	Ferranti.	Appointed as engineer to Grosvenor Gallery Company.
1886	Hopkinson (J. and E.).	Paper on "Dynamo-Electric Machinery" before Royal Society on 15 April, 1886.
1887	Heaviside.	Importance of inductance on long-distance telephony.
1887	Hertz.	Oscillation experiments and wave transmission.
1888		Ferranti's Deptford scheme begun.
1888	Tesla.	Invention of two-phase motor.
1889		Faraday House Electrical Engineering College established.
1889	Dobrowolski.	Invention of three-phase system.
1890		Fareham Urban District Council Supply begun.
1891		Lauffen-Frankfurt transmission of electric power over a distance of 175 km at 15 000 volts.
1891		St. Pancras Borough Council Supply begun.
1892		Niagara Falls electric power scheme commenced with two-phase current.
1892		Bray Urban District Council. Supply begun.
1893	Heaviside.	Publication of "Electro-magnetic Theory," 3 vols., 1893–1912.
1895	Röntgen.	Discovery of X-rays.
1896	Becquerel.	Discovery of radio-activity.
1896	Marconi.	First patent for wireless.
1896		Zeeman effect.
1897		First transmission of wireless signals across sea (Flatholm to Lavernock).
1897	Thomson (J. J.).	On the electron.
1898	Curie.	Discovery of radium.

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Date.	*Name.*	*Nature of Discovery, Invention, etc.*
1899	Pupin.	Patented particular distribution of inductance on line.
1899	Duddell.	Arc oscillation described at meeting of I.E.E. (13th April).
1902	First Atlantic wireless signals.	
1903	Poulsen.	Continuous-wave wireless by oscillating arc generator.
1904	Tungsten squirted filament for lamps (Just and Hanaman's Process).	
1904	Tungsten wire lamp patented.	
1904	Fleming.	Rectifying valve patented (16th November).
1905	Tantalum lamp introduced (Patented 1901 and 1902).	
1907	de Forest.	Three-electrode valve patented.
1913	Gas-filled lamp introduced.	

The following portraits will be found on the Plates indicated :—

	Plate		*Plate*
Mr. Ll. B. Atkinson	VI	Mr. R. A. Chattock	VII
Mr. F. Bailey	V	Col. R. E. Crompton	IV
Mr. O. H. Baldwin	IX	Mr. H. J. Dowsing	IX
Sir Charles Bright	X	Mr. B. M. Drake	VI
Sir T. O. Callender	V	Dr. W. H. Eccles	III
Mr. H. Edmunds	VIII	Prof. E. W. Marchant	III
Sir K. Elphinstone	XI	Mr. S. Morse	VIII
Mr. W. B. Esson	VIII	Sir William Noble	VI
Mr. S. Evershed	IV	Sir C. A. Parsons	VII
Dr. S. Z. de Ferranti	V	Mr. G. W. Partridge	VI
Prof. J. A. Fleming	IV	Mr. W. H. Patchell	V
Mr. E. Garcke	IV	Mr. C. C. Paterson	III
Sir R. T. Glazebrook	VII	Mr. C. F. Proctor	IX
Prof. A. Gray	X	Mr. H. W. Ravenshaw	X
Mr. F. E. Gripper	XI	Dr. A. Russell	VII
Mr. K. Hedges	IX	Mr. H. M. Sayers	IX
Mr. J. S. Highfield	III	Mr. A. Siemens	VII
Mr. H. Hirst	XI	Mr. D. Sinclair	XI
Mr. J. H. Holmes	IX	Mr. G. Sutton	XI
Mr. W. Judd	VIII	Mr. J. Swinburne	V
Dr. G. Kapp	VII	Mr. A. A. C. Swinton	III
Sir J. Kemnal	XI	Mr. J. C. Vaudrey	X
Sir A. Kennedy	IV	Mr. A. H. Walton	VIII
Dr. A. E. Kennelly	X	Mr. C. H. Wordingham	VI
Mr. J. E. Kingsbury	VI	Mr. A. Wright	VIII
Sir Oliver Lodge	IV		

and also those of

Michael Faraday	I	Sir William Siemens	II

TUESDAY, 21 FEBRUARY, 1922, AT 3 P.M.

(Held in the Institution Lecture Theatre.)

Mr. A. A. Campbell Swinton, F.R.S., Vice-President, in the chair.

The Chairman : It is with very great regret that I have to announce that our President, Mr. Highfield, has been suddenly seized with an illness which prevents his attendance to-day. Although it is not of a grave character, it is sufficiently serious to prevent his leaving the house. It is really somewhat of a tragedy, because the whole idea of the Commemoration Meetings is due to him, and I am sure he must feel very deeply disappointed at being prevented from attending. I think we cannot do less than send him a vote of commiseration, expressing the hope that he may make a speedy recovery and that, if he cannot be present at the Meetings to-morrow, he will at any rate be able to attend before they finish on Thursday.

The resolution was then put to the meeting and carried unanimously.

The Chairman : I now come to the subject of the lecture. Professor Fleming requires no introduction from me. By his work and writings, and more especially by his invention of the thermionic valve, his fame is now known in electrical circles all over the world. I shall therefore merely call upon him to give his lecture on "Michael Faraday, and the Foundations of Electrical Engineering."

MICHAEL FARADAY, AND THE FOUNDATIONS OF ELECTRICAL ENGINEERING.

By **Professor J. A. FLEMING, M.A., D.Sc., F.R.S.,** Member.

As we enter the hall of the Royal Institution of Great Britain in Albemarle-street we see facing us Foley's fine statue of Michael Faraday arrayed in the robes of a Doctor of Civil Law. In his hand he holds a ring-shaped object the original of which, by kind and special permission of the managers, I have been allowed to place on the table. That iron ring with its overwound spirals of wire is an almost sacred relic. It is one of the original pieces of apparatus with which Faraday made the great discovery of the induction of electric currents. It is the first induction coil, the primitive transformer, the progenitor of the dynamo machine and may be rightly regarded as the foundation stone of modern electrical engineering.

When the invitation came to me through our President to give an address in connection with these Jubilee meetings on some scientific topic relating to the activities of this Institution, it seemed possible that the time might well be spent in reviewing once more the manner in which Faraday's purely scientific researches in electricity and magnetism laid the foundations of a large part of all the great technical applications of these agencies which have since arisen.

At the present time when this laboriously gained

knowledge has been systematized and expressed in compact language, in short, "peptonized" for the benefit of students, we are apt to lose sight of the immense genius which enabled its originator to unravel the complicated results of new experiments and embrace them in simple comprehensive statements. Then again, we are so keen in the present day to find what we call practical applications of scientific research that we are prone to forget that the most valuable technical discoveries have very often arisen, not out of investigations having such utility as their immediate goal, but out of researches which had at the time no other object than a disinterested increase of our knowledge of the facts and laws of nature.

At the present time, and under the pressure of modern life, I doubt if one electrical engineer in a hundred has ever had time to read carefully through the three large volumes of Faraday's "Experimental Researches in Electricity," yet it is not only interesting but stimulating and educative in many ways to follow historically the footsteps of great pioneers and note the manner in which they dealt with new and difficult investigations.

The writings of Faraday have in this respect great value because he tells us about his failures as well as his successes. He takes us into his confidence as to the lines of thought that led him to his results, and as we see this master workman wielding his tools we are tempted to believe that we too, if we had the opportunity, might copy his methods and become great discoverers.

As it would be beyond the limits of possibility to deal exhaustively in the space of an hour with the electrical researches of Faraday in 30 years, I propose to limit our study of it to four portions of that work tracing out the main results connected with,

(1) The discovery of the induction of electric currents, and magneto electricity; which led finally to the invention of the magneto-electric machine, the induction coil, the dynamo and the transformer.

(2) His electrostatic investigations and researches on specific inductive capacity and electrostatic capacity generally, which explained effects noticed in the early use of underground and under-water cables and prepared the way for much other industrial work.

(3) The electro-chemical researches and researches on voltaic action which laid the firm basis for electro-chemical industries, and for great advances in electrical theory; and lastly with

(4) Faraday's electro-optical work and his theoretical views which have stimulated, in a very large degree, the scientific thought of his successors, such as Kelvin, Maxwell, and J. J. Thomson.

Faraday, as we know from the admirable biographies of him written by Bence Jones, Tyndall, J. H. Gladstone, Clerk Maxwell, and S. P. Thompson, was appointed assistant to Sir Humphry Davy at the Royal Institution in March 1813 when he was 22 years old, and his earliest original work there, following Davy's leading, was chemical and electro-chemical in character.

The great discovery by Oersted in July 1820 of the magnetic field round the wire joining the terminals of a voltaic battery, and the subsequent brilliant investigations of Ampère, had turned the attention of numerous scientists to this new field of electro-magnetism.

Oersted had pointed out in the Latin thesis announcing his discovery that round this wire "the electric conflict," as he terms it, "performs circles"; in modern language, that the lines of magnetic force are circular lines embracing the current-carrying wire. The suggestion then arose whether a magnet could be made to rotate round the wire, but the difficulty presented itself that the magnet has two inseparable poles and these tend to rotate round the current in opposite directions.

Faraday made his first important contribution to electrical science by solving this experimental problem in a particularly neat way in September 1821. The result, however, brought him into controversy with Wollaston, who had previously tried an experiment on the subject. Nevertheless it turned Faraday's thoughts to another problem, namely, whether a magnet could produce an electric current. Ampère had by that time demonstrated the identity of a spiral wire conveying an electric current with a permanent magnet as regards external magnetic effect, and also had discovered the electro-dynamic actions of conductors conveying electric currents.

Faraday knew well that an electric charge on an insulated conductor calls forth an induced charge of opposite sign on all surrounding conductors, and with a strong belief in the guidance of physical analogies he asked himself whether it was possible that an electric current in one wire could create another current in a neighbouring circuit.

In December 1824 he attempted unsuccessfully to obtain an electric current by the aid of a permanent magnet.

In the following year William Sturgeon gave to the scientific world the method of forming strong electro-magnets by surrounding bars of soft iron with current-carrying copper-wire spirals. Faraday then returned to the subject, and in December 1825 and also in April 1828 he stretched alongside of a wire connecting the poles of a voltaic battery one connecting the terminals of his galvanometer. A very little step often separates failure from success in experimental work. In the case of this experiment by Faraday, the failure may have been due to the fact that he closed his battery circuit before completing the galvanometer circuit, and hence he had to record of it that it gave "no result." It proved at least that a steady current in one wire does not produce a steady or continuous current in a proximate wire. Three years passed and then again the subject attracted Faraday's thoughts, and this time with brilliant and ever memorable results.

On the 29th August, 1831, he made the discovery by which he will be for ever known. In the laboratory note-books of the Royal Institution he thus described his experiment: "I have had an iron ring* made (soft iron), iron round and $\frac{7}{8}$ inch thick and ring 6 inches in external diameter. Wound many coils of copper

* A photograph of the ring coil which Faraday used is reproduced in Plate XIV.

round one half of it the coils being separated by twine and calico; there were three lengths of wire each about 24 ft. long, and they could be connected as one length or used as separate lengths. Will call this side of the ring A. On the other side but separated by an interval was wound wire in two pieces together amounting to about 60 ft. in length, the direction being as with the former coils. This side call B. Made the coil B side one coil and connected its extremities by a copper wire passing to a distance and just over a magnetic needle (3 ft. from wire ring) then connected the ends of one of the pieces on A side with battery; immediately a sensible effect on the needle. It oscillated and at last settled in its original position. On breaking connection of A side with battery again a disturbance of the needle."

It appeared then that the primary current merely produced a wave of secondary current, both at its commencement and cessation, but no effect during its continuance.

Knowing full well that the steady primary current kept the iron ring magnetized, it occurred to Faraday to produce the effect by the aid of permanent steel magnets only.

Hence on 24th September he wound over an iron bar with a helix of insulated wire. This wire he connected to the terminals of his galvanometer. He then brought down on the ends of the iron bar the opposite poles of two steel bar magnets and found a similar wave of secondary current when the magnets were placed in contact with or removed from the ends of the iron bar.

But the full meaning of this was not yet apparent, so on 1st October he wound on a wooden block an insulated copper wire 203 ft. long, and over it another insulated copper wire of equal length. One circuit was then connected to a galvanometer and the other to a battery of 100 cells. Faraday then noticed that at the instant the current began to flow in the wire connected with the battery a brief current in the opposite direction traversed the other adjacent circuit; whilst at the moment the battery current was arrested a transient secondary current in the same direction occurred in the galvanometer circuit. The clue to the explanation of these effects was now in his hand, and on 17th October, the fifth day of his work, he was able to realize his expectations and obtain an electric current from a permanent magnet.

"A cylindrical magnet," he wrote in his laboratory book, "had one end just inserted into the end of a helix of wire 220 ft. long. It was then quickly thrust in the whole length and the galvanometer needle moved; then pulled out again, and again the needle moved, but in the opposite direction."

Faraday had probably even at that time learnt to think of a magnet as carrying with it in all its movements its system of lines of magnetic force. Hence it was clear that in thus thrusting a magnet into a coil the convolutions were "cut" or crossed by these lines of force. He was therefore led to see that the production of the induced current was conditional on this "cutting" taking place. The ninth day of his work, viz. 28th October, saw these ideas put to further test.

Taking a large permanent horse-shoe magnet belonging to the Royal Society (see Plate XIV), he placed a copper disc between its pole pieces so as to form a strong transverse magnetic field through the disc normal to its circular surface. The galvanometer wires were connected to spring contacts which rubbed against the centre and the periphery of the disc. When the disc was rotated each radial portion cut across the lines of force and a steady electric current was found to flow through the galvanometer which reversed its direction either by reversing the rotation of the disc or the direction of the field.

Thus Faraday realized at last his original desire of obtaining an electric current from a permanent magnet; and he gave the world the first magneto-electric machine by which the energy expended in causing rotation of a disc was in part at least converted into energy of a direct electric current.

On 4th November, the tenth day of his work, Faraday brought this idea to its final test. Forming the end of the galvanometer circuit into a simple loop of wire he passed this loop through the field of his permanent magnet in such a fashion that one side cut across the lines of the field, and he found that whatever movement of the wire was accompanied by such cutting of the lines of force not balanced by an equal but opposite cutting in some other part, produced a current in the galvanometer circuit which lasted whilst that cutting took place.

Thus in 10 days of actual work during the three autumn months of 1831, Faraday not only discovered the facts of current induction and magneto-electric induction as well, but embraced them all in the statement of one great generalization of the utmost simplicity.

In his first announcement of results he considered that the secondary circuit, whilst the primary current was flowing near it, or whilst it was on the field of the magnet, was in a special state which he called the "electrotonic" state. He came afterwards to see that this state was merely that the secondary circuit was linked with or perforated by the lines of magnetic force due to the primary current or to the magnet.

Later on, the whole of the facts were summed up in a comprehensive statement which has been called Faraday's Law of Induction, and is as follows:—If any conducting circuit is placed in a magnetic field, and if by motion or change of shape of that circuit, or change in the direction or strength of the field, the total magnetic flux linked with the circuit is altered, it creates in it an electromotive force proportional at any instant to the time rate of change of the total flux linkage of field and circuit. This statement affords a sufficient basis for all practical calculations, but we shall reserve until later a discussion of the probable physical interpretation of this production of electromotive force in a circuit by the variation of the magnetic flux linkage with it.

Faraday recognized quite early in the course of his work that multiplying the number of turns of the secondary circuits increased the electromotive force induced in it, and one of the experiments in which he took particular pleasure was that of obtaining an electric spark from a permanent magnet and coil of wire. He wound a coil of many turns of insulated

wire on an iron bar and to one end of this wire attached a copper button amalgamated with mercury. The other end of the wire was also amalgamated and bent so as just to touch the button. The bar was then put across the poles of a horse-shoe magnet and pulled off suddenly. The jerk just separated the ends of the wire circuit and at that instant the induced E.M.F. created a small spark at the point of separation. It is needless to point out that the magneto-ignition used to-day with internal combustion engines is only a modification of this apparatus of Faraday. The operation of every taxicab or aeroplane is rendered possible only by the application of Faraday's spark obtained from a permanent magnet. A view of the apparatus which Faraday used for the above experiment will be found in Plate XIV.

On the 24th November, 1831, Faraday read to the Royal Society of London the paper which forms the First Series of his "Experimental Researches," in which he described these epoch-making discoveries. In it he amplified and extended his observations with full explanations and applied the deductions to explain other previously noticed effects, such as the damping action of a copper plate on the vibrations of a compass needle, discovered by Arago. So exhaustive was this treatment of the subject that no one has since added a single new fact or principle which is not implicitly contained in the record of this work thus given to the world.

Faraday reserved, and rightly so, his great talents for the discovery of scientific truth, and left it to others to amplify or apply the new knowledge. Hence he did not spend time on technical applications. These, however, quickly followed. Soon after the reading of Faraday's paper, Dal Negro and also H. Pixii produced machines in which a permanent horse-shoe magnet had its poles revolved in proximity to two fixed coils of insulated wire having iron cores so as to alternate the magnetic flux perforating the coils. This machine produced therefore an alternating induced current, but a year later Pixii added a form of commutator by means of which the current in the external circuit was converted to a pulsatory but unidirectional current. In 1833, J. Saxton and, in 1835, E. M. Clarke followed with the invention of similar magneto machines in which the magnets were stationary and the coils revolved.

In 1838, W. Sturgeon invented the simple split-ring commutator which thereafter became the usual method of rectifying the alternating induced currents in the armature coils.

In 1849, large compound magneto machines were made by Nollet, and a little later Holmes constructed similar machines giving an alternating current for operating an electric arc lamp at the South Foreland lighthouse. One of these last machines is to be seen downstairs in the basement of this building.

In 1856, Werner von Siemens devised the shuttle-wound armature revolving between curved pole-pieces to intensify the field.

In 1860, Antonio Pacinotti invented the ring form of armature, subsequently re-invented by Z. T. Gramme in 1870, and this with the multi-bar commutator gave us a practical form of direct-current machine.

About 1867, a number of inventors had clearly realized the practicability of self-excitation when using electro-magnets as field magnets, and self-exciting shunt- and series-wound dynamos were soon efficiently constructed. To these machines Werner Siemens gave the name "dynamo-electric machines."

In 1873, Von Hefner Alteneck modified the Siemens shuttle-wound armature into the earliest form of drum winding with multiple-bar commutator. From and after that date we may say that the modern period of dynamo construction began, based upon a scientific study of the principles involved. Great, however, as have been the improvements in mechanical construction and in the design of the various parts and elements of this most wonderful appliance for the transformation of energy from mechanical to electrical form, it is in principle only an elaboration of Faraday's copper disc and magnet with which he first produced a continuous current by rotation in a magnetic field.

Here also it may be pointed out that the most perfect form of machine for the absolute determination of electrical resistance, viz. the Lorentz apparatus as designed by the late Professors Viriamu Jones and W. E. Ayrton for the National Physical Laboratory, is only a Faraday copper disc generator in which the mutual induction of the circular field coil and of the coaxial revolving disc is accurately known.

This is then perhaps the place to make a reference to Faraday's discovery of the important quality of an electric circuit we call its "inductance," which was the subject of his Ninth Series of his "Experimental Researches." He tells us that this investigation originated in a question put to him by a Mr. Jenkin, viz. why it was that the separation of the two terminal wires of a single voltaic cell when held in the two hands gave no shock if the wire was short, but gave a strong shock if the wire included the coils of an electromagnet as part of its circuit.

Faraday worked his way by skilfully devised experiments to the conclusion that it was due to the induction of the circuit on itself, and that just as the arrest of a current in a circuit induces an electromotive force in the same direction in a parallel adjacent circuit, so also it induces an adjuvant electromotive force in its own circuit. He proved this by a very simple yet perfectly conclusive experiment. To this property of a circuit Faraday gave the name of "self-induction."

Our modern way of viewing the facts is to say that the circuit is self-linked with the magnetic flux due to the current in it, and that the arrest of this current by removing the flux creates a transitory electromotive force in the circuit in the same direction as the impressed E.M.F., but which may be far greater. We all know by experience the dangerous effects caused by the sudden opening of the circuits of a field magnet or other long supply circuit, and also the manner in which this quality called the inductance becomes of great importance in the case of high-frequency alternating currents.

We must, however, accord to Joseph Henry in the United States the credit of being a quite independent discoverer of this quality called the inductance of a circuit. Henry's researches stimulated the work of

Page and that of Sturgeon, and this in turn led Callan in Ireland to construct induction coils with thick primary and fine wire secondary coils. Time would fail me if I were to attempt to describe the details of the stages by which the induction coil was perfected by Callan, Page, Ruhmkorff, Apps, and others; also the manner in which it was modified progressively into the modern alternating-current transformer by Jablochkoff, Gauland and Gibbs, Zipernowsky and Deri, Ferranti, Mordey and Lowrie-Hall, and Berry. The older members of the Institution will remember all the details and difficulties of the early days of alternating-current electric supply.

We next turn to consider Faraday's work in connection with dielectric phenomena.

The early workers in electrical science, Franklin, Dufay, Cavendish, and others had discovered that an electrically charged insulated conductor calls forth a charge of opposite sign on neighbouring conductors. To this action the name "induction" had been applied. The mathematical physicists, Coulomb, Poisson, and others had been content to view this simply as an action-at-a-distance effect.

Faraday, however, shared with Newton an intense reluctance to accept the view that a physical action can take place at a distance without the aid of any intervening mechanism, and he tells us in the Eleventh Series of his "Experimental Researches" that he was led to believe that this electrostatic induction was in all cases an action of contiguous particles of the insulator or medium separating the two conductors.

The first great fact that he established by experiment was the impossibility of giving an absolute electric charge to matter or of creating a charge of electricity of one sign without creating an equal quantity of the opposite sign. When he viewed these electrostatic actions in the light of the experience he had gained in dealing with magnetic fields and electromagnetic induction, he was enabled to visualize the electrostatic field as traversed by straight or curved lines of electric force or induction which terminated always on charges of opposite sign. A more advanced conception subsequently prevailed, viz. that of a tube of electric induction or a tubular surface bounded by lines of electric force or induction, the charges on its terminal orthogonal sections being equal but of opposite sign.

Every case of electric charge was therefore only a particular instance of a form of condenser or Leyden jar. A classical experiment of Faraday's in this connection is the one generally called the "ice pail experiment," from his use of a pewter ice pail (see vol. ii, "Experimental Researches," etc., p. 281). To show it properly requires, however, a metal canister with a lid. Through this lid is passed a silk thread which sustains a metal ball so that the ball and lid can be lifted together. The canister is placed on a gold-leaf electroscope and the ball is given a small positive charge. The canister is then earthed and the ball lowered into it. If the canister is then insulated the electroscope shows no charge. If the ball is then tilted so as to touch the inside of the canister and then withdrawn, the electroscope still shows no charge. This proves that the negative induced charge on the inside of the canister is exactly equal to the positive charge on the ball.

The question then at once arose how far the nature of the insulating material, or dielectric as Faraday called it, affected the charge taken up for a given potential difference of the condenser plates. Faraday did not know in 1837, at the date when he undertook these researches, that the celebrated Henry Cavendish, that recluse philosopher who had such a strange and, to us, incomprehensible reluctance to publish the results of his researches, had 66 years previously anticipated him in experiments on this subject. Cavendish, as we learn from his original papers first published by Clerk Maxwell in 1879, had in 1771 measured the electrical capacity of plate condensers made with plates of glass, shellac and beeswax and compared them with the capacity of air condensers with metal plates of the same size and distance apart, and had given numerical values for the "specific inductive capacity," as Faraday afterwards termed it, of these substances.

Faraday attacked the problem in a slightly different way. He prepared two identical Leyden jars each consisting of a metal ball enclosed in a spherical metal case, the interspace being capable of being filled with a solid, liquid or gaseous dielectric (see Plate XIV). He evidently selected this form of condenser rather than a flat plate type as used by Cavendish, in order to avoid any difficulties connected with edge or fringe effects.

His method of procedure was to charge one jar to a known potential as indicated by a Coulomb torsion electrometer. He then divided that charge with the other condenser by bringing the inner and outer coatings respectively in connection, and measured in the same way the common potential of their inner coatings. Suppose then that C_1 and C_2 denote the capacities of the two condensers, and that C_1 is charged to a potential V_1, whilst after division of the charge the resulting common potential is V_2. Then on the assumption that there is no leakage or loss of charge we have the equation

$$C_1V_1 = C_1V_2 + C_2V_2$$

or

$$\frac{C_2}{C_1} = \frac{V_1 - V_2}{V_2}$$

The electrometer readings gave at once the ratio of the fall in potential $V_1 - V_2$ to the common potential V_2, and hence the relative capacities of the condensers were determined.

Experimenting in this manner with the interspace of one condenser filled in with various solid dielectrics such as shellac, glass, spermaceti, beeswax, etc., Faraday determined the proportion in which the air-condenser capacity is increased when these substances take the place of the air, and he called these numbers the "specific inductive capacities" of these substances. Faraday's term is preferable to the modern expression "dielectric constant," because subsequent experiment showed that this ratio is anything but constant and varies with temperature, time of charging, and other factors in a high degree.

At a subsequent date when Maxwell had enunciated his theory of the propagation of electromagnetic actions through dielectrics, the measurement of this coefficient

became of great importance and has given rise to a vast amount of investigation. The date when Faraday made known his discoveries on these dielectrics was in November 1837, the year in which the first practical construction of telegraph lines was begun by Cooke and Wheatstone. Hence they had immediate importance in connection with the soon discovered capacity effects in subterranean and subaqueous cables.

Sixteen years later Faraday had the opportunity of studying some of these effects in connection with long insulated conductors with the aid of facilities afforded to him by Mr. Latimer Clark, and these he records in the Third Volume of his "Experimental Researches."

Faraday was the first to point out that a subterranean or subaqueous insulated copper wire is merely a form of Leyden jar, and he analysed and explained many of the effects due to its static charge and those also called by telegraph engineers the "absorption of the dielectric."

These researches of Faraday on the electrostatic capacity of cables were published in 1854, and it is possible that they had some influence in directing the attention of Lord Kelvin (then Professor William Thomson) to the subject, with the result that the latter gave to the world in 1855 his classical paper on "The Theory of the Electric Telegraph," which laid in turn the firm foundation for a true theory of the submarine cable and for immense advances in practical cable telegraphy.

In relation to this subject, it is worth noting that Faraday was one of the first to notice the value of gutta-percha as an insulator. In 1848 he sent a short paper to the *Philosophical Magazine* describing his experiments with it.

Gutta-percha as a dielectric deviates from other insulators in a remarkable manner. For one thing its specific inductive capacity diminishes far more rapidly than that of most other dielectrics as the frequency of the alternating electromotive force with which it is tested is increased. Again, its true conductivity for alternating currents increases very rapidly with the frequency, a fact well known to telephone engineers. It is interesting to note that Henry Cavendish made measurements in 1771 or 1772 of the dielectric constant of various kinds of glass and these agree remarkably well with those made by the late Dr. John Hopkinson a century later. Cavendish also had considered the case of stratified dielectrics, a subject of the greatest importance in cable insulation.

We must next pass briefly in review Faraday's great contributions to electro-chemistry and electrolysis.

The power of the electric current to effect chemical decompositions was one of the earliest facts noticed, after Volta's invention of his pile, by Nicholson and Carlisle. Sir Humphry Davy's great discoveries soon after led the way to an immense accumulation of facts in electro-chemistry. It needed, however, the genius of Faraday to bring order out of this chaos. Faraday possessed in an almost unique degree the power of skilful experimental work united to a limitless ingenuity in devising the simplest means of attaining his ends, but, above all, with intellectual insight of commanding power enabling him to draw out from a mass of facts great generalizations which connected them together and presented them as the results of some fundamental law or principle.

A preliminary investigation which occupies the Third Series of his "Experimental Researches" was concerned with the identity of the electricities produced in various ways, viz. by the frictional machine, the voltaic pile, electromagnetic induction and thermopiles, and by animal organs. He proved by strict experiment that each of the above sources could produce an electric current which in various degrees had the same power of producing heat, chemical action, magnetism, and muscular contraction, and were therefore identical in nature.

This research unified in a remarkable manner the various departments of electrical science and showed that an electric current, no matter how produced, consists in a movement of electricity due to a certain electromotive force or potential difference in conductors of a certain resistance.

Recognizing then the necessity for a certain reform in nomenclature with regard to electro-chemical phenomena, Faraday revised the terminology and coined certain words which have become permanent possessions.

These words "electrolyte," "electrolysis," "electrode," "ion," "anode," and "cathode" are so familiar to us all that we need not waste a moment in defining them.

Faraday's first great contribution to the subject was the experimental proof he gave that in electrolysis the mass of either ion carried to the electrodes is exactly proportional to the quantity of electricity that has passed through the electrolytic cell—no matter how that quantity has been produced or under what electromotive force it is set in motion. Hence he gave us a new instrument, the voltameter, by means of which quantity of electricity could be measured by the observation of the volume, at standard pressure and temperature, of a gaseous ion such as hydrogen or the weighing of a metallic ion such as silver or copper. It is needless to remind my audience that our practical definition of the ampere as a unit of current is based upon Faraday's first Law of electrolysis, and that by International Conventions the electric current of unvarying strength which when passed through a neutral solution of nitrate of silver containing 15 parts by weight of salt to 85 of water, using a silver anode and platinum cathode, deposits silver at the rate of 0·001118 gramme per second is defined as the unit of electric current and called the "ampere."

In the earliest days of commercial electric lighting, the electrolytic sulphate of zinc meter was adopted by Edison as a form of house meter, and at one time the best, though not most speedy, method of calibrating an ammeter was by the weight of copper deposited by a current which passed through the ammeter and a sulphate of copper voltameter. Faraday also enunciated a second law of equal importance—also based on exact experiment—viz. that when the same current passes through a number of voltameters in series it deposits on each electrode masses of ions which are exactly proportional to their chemical equivalents.

Faraday also studied with great care the secondary

reactions which take place in the electrolytic cell. He also showed that in the voltaic cell the production of a certain quantity of electricity was associated with a certain definite equivalent chemical action. Thus the solution (apart from local action) of 32·44 grammes of zinc in the voltaic cell results in the movement of 96 340 coulombs of electricity across every section of the circuit as measured by the time integral of the current generated.

In the Eighth and also in the Sixteenth Series of his "Experimental Researches" he examined with great care the source of the electromotive force of the voltaic pile. He championed the view at one time called the chemical theory, as opposed to the contact theory espoused by Volta. These conflicting opinions led to one of the historic controversies of electrical science, into the details of which we need not, however, enter.

Perhaps the most important outcome of Faraday's work on electrolysis was the deduction made by Von Helmholtz, in a lecture given in 1881 before the Chemical Society, that Faraday's laws imply that if matter is atomic in structure then electricity must be atomic in structure also.

Since there is a definite quantity of electricity associated with the chemical equivalent in grammes of an ion, it follows that if there is a minimum mass of any elementary body, say silver, which we call a monovalent atom or ion, then there must be also a minimum indivisible quantity of electricity associated with it in electrolysis. This quantity may be called an atom of electricity.

Maxwell employed the term a molecule of electricity in his treatise. Johnstone Stoney subsequently named it an electron.

Although Faraday discussed in various parts of his writings on electrolysis the phenomenon once called the polarization of the electrodes and alluded briefly to the secondary piles of Ritter, he did not pursue the subject. Nevertheless, all subsequent work by Planté, Faure, Edison, Swan and others, which ultimately gave us the secondary cell or storage battery as well as the immense electro-chemical industries in the production of electrolytic copper, aluminium and zinc, must be regarded as an outcome of Faraday's fundamental work on the laws of electrolysis and electro-chemical phenomena.

We must then consider shortly, and in the last place, some of Faraday's more purely scientific work—which, though not resulting immediately in such practical achievements as some of that already described, has yet had enormous influence in stimulating the thoughts of his scientific successors and indirectly bringing to us benefits and discoveries of incalculable value.

One of the most brilliant of these is that described in the Nineteenth Series of his "Researches," published in 1845 and entitled "The Magnetization of Light." Faraday at one time prepared a sample of glass of great density the composition of which was a boro-silicate of lead. Placing a prism of this glass having polished ends in the field of a powerful electromagnet with the greatest length of the glass in the direction of the lines of magnetic force, he found that when the magnet was excited, the glass became possessed of the power of rotating the plane of polarization of a ray of light in a manner similar to that which quartz, sugar solution and some other substances do naturally. There is, however, one great difference. If the rotation is natural, that is, produced by some molecular structure, as in quartz or sugar solution, the rotation is reversed in direction if the ray is reflected back through the medium and hence destroyed altogether by the double journey there and back. In the case of the magnetic rotation, the rotation for diamagnetic bodies like heavy glass is always in the direction of the helical current which would produce the magnetic field. Hence the angular rotation is doubled by reflecting the ray back again. Accordingly it can be detected, when very feeble, by the device of reflecting the ray to and fro several times along the prism in the direction of the magnetic field. Faraday discovered several substances in which this magneto-optic rotation exists, and Verdet subsequently found that in paramagnetic bodies like ferric chloride solution it is in the opposite direction to that in diamagnetic bodies. The full theory of the effect is somewhat complicated, but Lord Kelvin held that Faraday's discovery of this effect demonstrated the reality of Ampère's explanation of the nature of magnetism, and Maxwell states that it affords good evidence that some kind of rotation is taking place in a magnetic field, the axes of rotation being the directions of the lines of force.

For more than 30 years the above fact remained the only magneto-optic effect known, until Dr. Kerr discovered in 1877 a rotation in the plane of polarization of a ray of light reflected from the polished iron polar surface of an electromagnet.

Kundt subsequently discovered the extraordinarily large rotations of the plane of polarized light when passing through semi-transparent films of iron, nickel, or cobalt which have strong magnetic fields created by an electromagnet normal to their surface. In 1897, Zeeman discovered that if a source of light yielding spectral lines is placed in a magnetic field the single lines are doubled or trebled.

Faraday's genius and vast analytical powers were never seen to greater advantage than in that great series of researches described in his Third Volume, in which he investigated the magnetic properties of matter generally and drew out from the multitude of his observations broad generalizations and principles which command our admiration by their wonderful beauty and simplicity. Operating with his great electromagnet he found that a prism or bar-shaped sample of any material whatever when suspended in a strong magnetic field sets itself with its greatest length or at least some axis in it, either along or else transversely to, the lines of the field.

Analysing these effects more carefully, he found that homogeneous and non-crystalline substances might be divided into two great classes, viz. magnetic and diamagnetic. The former, when placed in a non-uniform field, move from weak to strong parts of the field and the latter in the opposite direction. The magnetic bodies are furthermore divided into ferromagnetic, which are capable of acquiring magnetic polarity, whilst in the field, and the paramagnetic which do not.

Faraday was the first to notice the paramagnetic qualities of oxygen gas.

With profound insight into the meaning of these facts, Faraday saw that they might all be connected by the explanation that bodies differ in their power of conducting lines of magnetic force. The ferromagnetic and paramagnetic conduct better, or, to use Lord Kelvin's subsequently coined term, are more permeable to magnetic flux than empty space, and the diamagnetic are less permeable. Lord Kelvin, in "Papers on Electrostatics and Magnetism," says: "The singular combination of mathematical acuteness with experimental research and profound physical speculation which Faraday though not a mathematician presented, is remarkably illustrated by the use of the expression 'conducting power' of a medium for lines of magnetic force."

There is no doubt that Faraday had clearly grasped the analogy between an electric circuit with its power of conducting current as expressed in Ohm's law, and a magnetic circuit with its power of conducting magnetic flux, and he thereby laid the foundation for that treatment of the magnetic circuit with its varying permeability or reluctivity in its respective parts which has been so fruitful of results and, in the hands of innumerable subsequent investigators, reduced dynamo and transformer design almost to an exact science.

By applying these principles Faraday was enabled to give logical and satisfactory explanations of countless observed facts, and placed all subsequent workers in possession of clues capable of guiding them through the more complicated phenomena presented by the behaviour of crystalline substances in the magnetic field.

Then, in conclusion, it may be profitable to expend a moment or two in discussing some of Faraday's speculations regarding lines of force, electric and magnetic, which occupied the later years of his active life.

He had long accustomed himself to visualize the electric and magnetic fields as mapped out or traversed by these lines, the magnetic being defined as the lines along which a free marked, or so-called north, magnetic pole would move, and the electric by the direction in which a small, positively electrified conducting particle would travel.

A question to which he continually refers is whether these lines are mere geometrical conceptions like lines of latitude and longitude on the terrestrial globe, or whether they have some actual existence and may be regarded as the region or locality of some peculiar state or condition of the space.

It is clear that he came after a time to regard what we now call tubes of electric or magnetic force as having physical reality, so that they give a discrete or atomic character to the electric and magnetic fields.

In 1852 he published a paper, reproduced in the Third Volume of his "Researches," entitled "On the Physical Character of Lines of Magnetic Force." He had arrived at the conclusion that these tubes behave in some degree like elastic threads and that electric and magnetic attractions and repulsions may be explained as the result of the tendency of the tubes to contract in the direction of their length and press on each other laterally.

This idea was afterwards mathematically developed by Maxwell and by J. J. Thomson. If, then, there is a tension along a tube, it should be possible to propagate transverse vibrations along it as along a stretched rope or indiarubber cord, and accordingly in a previous paper published in the *Philosophical Magazine* in May 1846, entitled "Thoughts on Ray Vibrations," Faraday expounded the view, put forward tentatively, that light as a physical agent consists in rapid vibrations propagated along lines of force. He does not say whether electric or magnetic force.

A kinematic model capable of imitating these properties of a tube of magnetic force or induction might be constructed as follows. Imagine a number of small spherical bags of thin extensible material to be filled with liquid and the bags connected end to end by a little coupling at their poles. If then we imagine the fluid in each bag set in rotation round the polar axis, it would distort each bag into an oblate spheroid and the whole line of bags would contract but swell out laterally like a muscular fibre in contraction. If the ends of the row of bags were fixed, the rotation of the liquid would create a longitudinal tension and enable transverse vibrations to be propagated along the line. The model has also the additional feature that it involves rotation of some kind taking place along the axis line and, as we have seen, Maxwell considered this could be inferred from Faraday's discovery of magneto-optic rotation of the plane of polarized light.

Any mechanical model intended to represent the structure of the electromagnetic field must, however, take account of the interconnection of electric and magnetic forces established by Faraday's discovery of magneto-electric induction. This is best expressed by saying that the lateral or sideways motion of a line of magnetic force parallel to itself creates an electric force, which is at right angles to the direction of the magnetic force and to the direction of the motion. This was experimentally demonstrated in 1905 by Mr. H. A. Wilson with a cylinder of dielectric revolving in a strong magnetic field, and he verified Sir Joseph Larmor's expression for the electric force so created, viz.:

$$E = (1 - 1/K)\,\mu HV$$

where H is the magnetic force, V its orthogonal velocity, and K the dielectric constant. If the material is a metal then K is practically infinite and the formula reduces to Faraday's law:

$$E = BV$$

where B is the magnetic flux density.

Then there is a reciprocal principle, viz. that the lateral motion of a line of electric force parallel to itself with velocity V creates a magnetic force H such that $H = KEV$. This was experimentally demonstrated by Rowland's experiment with a rapidly rotating disc carrying an electric charge on its periphery, which was shown to produce a magnetic field similar to that of a circular wire carrying a current. The relation between the magnetic and electric forces is analogous to that between a vortex line or spin in a fluid and a squirt or jet of the fluid. The lateral movement of a

straight vortex can be shown to produce a displacement or jet of fluid, and the lateral displacement of a jet creates a vortex. In each case the relation of vortex line, jet line and velocity is that of three rectangular axes.

When Clerk Maxwell came to consider Faraday's mode of regarding the electric and magnetic fields he saw, as he tells us, that although Faraday was not a professed mathematician nor skilled in the use of mathematical analysis, yet his mode of viewing the phenomena was admirably adapted for mathematical treatment. Hence Maxwell proceeded to give its symbolical form.

Every vector or directed quantity may have some other vector associated with it which is called its "curl." The curl may be defined as the line integral of the vector taken round unit of area. Maxwell therefore expressed Faraday's Law of Induction in the following form:

$$-\dot{B} = \text{curl } E = \frac{4\pi}{\kappa} \text{ curl } D$$

where $-\dot{B}$ stands for the rate at which the magnetic flux is being removed from the circuit, and D is the electric strain or displacement along the boundary.

Then Maxwell also expressed in the same symbols Ampère's Law, viz. that 4π times the electric current through unit area is the curl of the magnetic force.

By a splendid stroke of genius, Maxwell saw that electric strain or displacement in a dielectric whilst it is changing is equivalent to a current and therefore should produce a magnetic force. Hence Maxwell's second equation for pure dielectrics is

$$4\pi\dot{D} = \frac{1}{\mu} \text{ curl } B$$

These two equations lead at once to a third pair, viz.:

$$\ddot{B} + \frac{1}{\mu\kappa} \text{ curl}^2 B = 0$$

$$\ddot{D} + \frac{1}{\mu\kappa} \text{ curl}^2 D = 0$$

These are well-known equations which express the fact that the magnetic flux and electric strain are not propagated through the field instantly but with velocity $1/\sqrt{(\mu\kappa)}$. The numerical value of this velocity can be determined from the ratio of the values of the capacity of a condenser reckoned in electromagnetic and in electrostatic units, and this velocity is identical with that of light for air and some other dielectrics. Hence Maxwell was able to propound his novel theory of the electromagnetic nature of Light. Later on G. F. Fitzgerald made the brilliant suggestion that Maxwell's electromagnetic waves should be produced by the discharge of a Leyden jar, and we all know how the attempt to verify Maxwell's view that electric displacement in dielectrics should create magnetic force led Hertz to the beginnings of his notable work, and laid the foundations on which has since been built up the grand edifice of modern wireless telegraphy and telephony.

This great practical achievement is the outcome of Maxwell's penetrating insight into the inner meaning of Faraday's ideas. In the light of Maxwell's interpretations, it is now easy to see the *modus operandi* of electric current induction.

An electric current in a wire consists in a drift or procession of atoms of electricity or electrons from which radiate lines of electric force. The lateral motion of these lines of electric force creates lines of magnetic force at right angles to the direction of the electric force and of the drift direction. Hence the magnetic force lies in circles centred on the axis of the wire. But this magnetic force does not spring into existence everywhere instantly. It moves outwards from the wire with a certain velocity. Hence if a second circuit is laid parallel to the first, it is "cut" by these expanding circles of magnetic force. This, however, creates an electric force at right angles to the direction of the magnetic force and to the direction of their advance.

This electric force is in the direction of the secondary circuit, and therefore urges the free electrons in the latter in the opposite direction to the movement of the free electrons in the primary circuit. When the magnetic field is fully formed, this secondary electric force ceases. Hence the secondary induced current in its circuit is a transitory current at "make" of the primary. When the primary current stops, the magnetic field is absorbed back again and the process of "cutting" the secondary circuit takes place in the reverse direction. Hence we have the opposite transitory induced secondary current at the "break" of the primary.

We are thus able to visualize the process and are led to regard these lines of force as probably localized affections or states of some continuous medium or æther. But what those states are, investigation has not yet revealed. It is hardly possible, however, to treat these theoretical questions at the present time except in the light of the Principle of Relativity which has enlarged our scientific ideas so much of late years. This theory might perhaps more appropriately be called a theory of Actuality. Its chief aim is to emancipate the descriptions of natural phenomena from the limitations imposed when they are considered as viewed by a single observer, and to state them in terms valid for all observers whatever their relative motion may be. Hence, having regard to the searching analysis to which our ideas of Space, Time, and Force have been subjected by Einstein and his predecessors and followers, it is not surprising that electromagnetic theory as given to us by Faraday and Maxwell has required extensive revision.

With respect to Faraday's tubes of electric and magnetic force viewed as in motion through space, Professor E. T. Whittaker has shown in a recent paper that they may then be regarded as projections in our three-dimensional space of surfaces he calls "calamoids" existing in a four-dimensional space-time continuum, which last have an objective reality that we cannot ascribe to Faraday tubes moving in our three-dimensional space. Moreover, these recent extensions of scientific thought have given some answer to a question which long and deeply occupied Faraday's mind, viz. a possible connection between gravitation, electricity and magnetism.

In the Twenty-fourth Series of his "Experimental

Researches" Faraday recounts many experiments he tried, with negative results, to find such a connection. But Einstein's Theory of Relativity predicted that a ray of light, which is an electromagnetic wave, would be deflected if it passed near a heavy gravitating mass. The observations made at the total solar eclipse on 29th May, 1919, confirmed, in the opinion of astronomers, this prediction by showing that light from distant stars was bent out of a straight line by the mass of the sun when the ray passed very near to it.

Here then we have a connection as sought for by Faraday between gravitation and electromagnetic effect. But I must pause.

In this brief sketch of Faraday's electrical researches, we have dealt only with the work and not with the man. Faraday, as we all know, was not only a prince of investigators; he was a truly great man. By his simple yet elevated character, his high aims, his freedom from all petty or personal ambitions, and his whole-souled devotion to the pursuit of scientific truth, he has made humanity his debtor as much by his personality as by his achievements. His influence may be said to dominate still the methods of the Institution in which that work was done.

The Royal Institution is without rival in the world for the unspeakable value of the contributions made to human knowledge in its laboratories and the ridiculously small cost at which those results have been attained. Sir James Dewar lately stated that the whole expenditure of the Royal Institution from the beginning of the nineteenth century to the present time for salaries of its professors, assistants, attendants and laboratory materials and appliances has been only £100 620. Gifts and donations have been few and far between. Its revenue has been derived almost wholly from membership subscriptions and lecture fees. But the applications of the great scientific discoveries made in its limited laboratory space have brought untold wealth to the Exchequers of nations. Who, for instance, shall evaluate the advantages in current coin of the ability to transmit water power to a distance by electrical means? Yet Faraday's discoveries lie at the root of it all.

It is in the power of all the members of this, almost the youngest and yet the largest of the great technical Institutions, to support one of the oldest of our purely scientific Institutions by seeking membership in it, and so, perhaps, repay part of their debt to it by making possible more discoveries, which may even surpass in value the researches by which Michael Faraday laid well and truly the foundations for the labours of the modern electrical engineer.

Sir Herbert Jekyll: It is my privilege to propose the vote of thanks to Professor Fleming. I am afraid that I am here in the character of an ancient monument, as I am the only one present of the original members of this Society which has now grown into a great and flourishing Institution. It gives me additional pleasure because I had the privilege, which is perhaps not shared by anybody in this room, of attending lectures by Michael Faraday. I was taken when quite a small boy to the lectures which he gave at the Royal Institution at Christmas and, although I cannot pretend to remember exactly the experiments which he showed, I have very little doubt that on that occasion we saw some of the actual apparatus which has been used to-day by Professor Fleming. What I do remember most distinctly is the extraordinary simplicity and kindliness of the man himself. All the boys used to sit round him on the front row of the benches, and the moment the lecture was over, exactly on the stroke of the hour, we all rushed forward to the table to ask him questions and hear further explanations of any points we did not understand. I remember very well that he was so simple and easy and kind to us all that it was the greatest pleasure to ask him anything, and he always had something to give us, either a bit of magnetized wire or some little thing which was very delightful to us boys. He lived at the Royal Institution, took the greatest interest in it, and always attended the lectures given there. There was one occasion when a lecture was given on the subject of Greek art by a very learned man who was not an expert lecturer. The lecture fell rather flat and, in order to save the situation, Faraday said, "Ladies and gentlemen, here is a halfpenny," and he talked for a quarter of an hour about the coin in such a delightful manner that the audience went away quite happy and satisfied. He saved the situation. He once told a story against himself. His apparatus was usually made by a certain Mr. Murray, a Scotsman. Faraday wanted a rather more than ordinarily complicated piece of apparatus made, and he explained it to Mr. Murray, saying, "If I give you a drawing of this, do you think you can make it?" Murray said: "There is nothing so foolish you will draw that I will not make." I am sure that we are all extremely obliged to Professor Fleming for his brilliant lecture; it is most illuminating and has given us the greatest pleasure. Therefore I tender to him, on behalf of this audience, our most appreciative thanks.

Mr. C. H. Wordingham: It gives me the greatest pleasure to second the vote of thanks. The way in which Professor Fleming has led us step by step through those most epoch-making inventions and investigations, and the manner in which he has shown us the actual apparatus used by the great discoverer, must, I think, have aroused a feeling of enthusiasm. Of all the things he said, the one which impressed me most was the fact that some of the greatest discoveries were crowded into a period of 10 days.

The motion was then put to the meeting and carried with acclamation. The meeting adjourned at 4.15 p.m.

ANNUAL DINNER.

The Annual Dinner of the Institution was held on Tuesday, 21st February, 1922, at the Hotel Cecil, at 7.30 p.m.

In the absence of the President (Mr. J. S. Highfield), who was unable to attend owing to illness, Dr. W. H. Eccles, F.R.S., Vice-President, presided over the gathering, which numbered about 500 persons.

Among those present were: The Rt. Hon. F. G. Kellaway, M.P. (*Postmaster-General*), The Rt. Hon. Lord Southborough, P.C., G.C.B., G.C.M.G., G.C.V.O. (*Honorary Member*), The Hon. Mr. Justice Sargant, The Hon. Sir Charles Parsons, K.C.B., F.R.S. (*Honorary Member*), Air-Marshal Sir H. M. Trenchard, Bart., K.C.B., D.S.O. (*Chief of Air Staff*), Sir Anthony Bowlby, K.C.B., K.C.M.G., K.C.V.O. (*President, Royal College of Surgeons*), Sir S. Chapman, K.C.B., C.B.E. (*Permanent Secretary, Board of Trade*), Sir R. T. Glazebrook, K.C.B., D.Sc., F.R.S. (*Past President*), Brig.-Gen. Sir H. C. L. Holden, R.A., K.C.B., F.R.S., Major-Gen. Sir A. M. Stuart, K.C.M.G., C.B., Prof. Sir W. H. Bragg, K.B.E., F.R.S., Sir James Devonshire, K.B.E. (*Honorary Treasurer*), Sir Arnold Gridley, K.B.E., Sir Andrew Ogilvie, K.B.E., C.B. (*Member of Council*), Sir William Pope, K.B.E., F.R.S. (*Acting President, Society of Chemical Industry*), Sir A. I. Durrant, C.V.O., C.B.E. (*H.M. Office of Works*), Sir H. C. Mance, C.I.E., LL.D. (*Past President*), Sir William Noble (*Member of Council*), Col. R. E. Crompton, C.B. (*Past President*), H. P. Hansell, C.V.O., M.A., G. W. Humphreys, C.B.E. (*Chief Engineer, London County Council*), P. V. Hunter, C.B.E. (*Member of Council*), C. D. le Maistre, C.B.E. (*Local Honorary Secretary, American Institute of Electrical Engineers*), C. H. Wordingham, C.B.E. (*Past President, I.E.E.*, and *Chairman, British Electrical and Allied Industries Research Association*), C. T. Allan (*Joint Hon. Secretary, Western Centre*), Ll. B. Atkinson (*Past President*), J. D. Bailie (*Hon. Secretary, North Midland Centre*), G. Balfour, M.P., Prof. E. Barker, M.A. (*Principal, King's College, London*), J. Bowden, O.B.E. (*Chief Supt. Ordnance Factories, Woolwich Arsenal*), W. E. Burnand (*Chairman, North Midland Centre*), A. Carpmael (*Honorary Solicitor*), H. J. Cash (*Member of Council*), R. A. Chattock (*Chairman, South Midland Centre*), J. R. Cowie (*Member of Council*), F. W. Crawter (*Member of Council*), E. P. Cumberbatch (*President, Electrotherapeutic Section, Royal Society of Medicine*), D. N. Dunlop, A. G. Ellis (*Hon. Secretary, North-Western Centre*), Dr. S. Z. de Ferranti (*Past President*), Dr. C. C. Garrard (*Past Chairman, South Midland Centre*), F. Gill, O.B.E. (*Member of Council*), E. T. Goslin (*Chairman, Scottish Centre*), Dr. H. S. Hele-Shaw (*President, Institution of Mechanical Engineers*), Captain H. Hooper (*Hon. Secretary, South Midland Centre*), J. E. Kingsbury, Lt.-Col. F. A. Cortez Leigh, T.D., R.E. (*Member of Council*), J. MacGregor (*Chairman, Cable Makers' Association*), Stanley Machin (*President, London Chamber of Commerce*), C. E. Musgrave (*President, Chartered Institute of Secretaries*), A. J. Newman (*Past Chairman, Western Centre*), Prof. J. W. Nicholson, F.R.S. (*President, Röntgen Society*), A. Page (*Member of Council, I.E.E.*, and *Electricity Commissioner*), C. C. Paterson, O.B.E. (*Vice-President*), Dr. A. Russell (*Member of Council, I.E.E.*, and *President, Physical Society of London*), Roger T. Smith (*Past President*), W. J. Squires (*Chairman, L.C.C. Highways Committee*), A. A. Campbell Swinton, F.R.S. (*Vice-President, I.E.E.*, and *Chairman of Council, Royal Society of Arts*), P. D. Tuckett (*Member of Council*), and P. F. Rowell (*Secretary*).

Before the dinner commenced the Chairman suggested that a telephone message should be sent to the President, expressing regret at his absence and wishing him a speedy recovery from his illness, and at a later stage of the proceedings the Chairman read a reply from the President to the message thanking the gathering for their greetings.

After the usual Loyal Toasts the Chairman announced that the following greetings had been received:—

BUCKINGHAM PALACE,
18 *February*, 1922.

J. S. HIGHFIELD, ESQ.

DEAR SIR,

I am desired by His Royal Highness The Duke of York to express to you and the members of the Institution of Electrical Engineers his best wishes for a successful Commemoration Dinner.

The Duke asks you to say how very sorry he is not to be able to be present at the Dinner, and he trusts that the Institution will continue to prosper and render the same yeoman service in the future as it has done in the past for the benefit and advancement of the science, commerce, and industry of this country.

Yours faithfully,
(*Signed*) LOUIS GREIG,
Comptroller to H.R.H. the Duke of York.

From American Institute of Electrical Engineers.

"Greetings occasion your fiftieth anniversary. Le Maistre our Honorary Secretary in London and W. B. Potter now in Paris have been cabled to represent us."

From French Society of Electricians.

"The President and Members of Council of the French Society of Electricians send to their colleagues of the Institution of Electrical Engineers an expression of their feelings of most cordial friendship on the occasion of fiftieth anniversary of the first meeting of the Institution."

From Italian Electrotechnical Association.

"Join heartily celebration fiftieth anniversary first meeting Institution wishing continuous increase prosperity and success"—*President*, DEL BUONO.

From Dutch Royal Institute of Engineers.

"Offer you cordial congratulations on fiftieth anniversary as leading Institution in promoting electrical science investigation and practice."

From Electrotechnical Section, Dutch Royal Institute of Engineers.

"Many congratulations fiftieth anniversary first meeting Institution Electrical Engineers."

From Association of Managers of Dutch Electricity Undertakings.

"Hearty congratulations on occasion celebration 50th anniversary first meeting of Society Telegraph Engineers."

From The Institution of Gas Engineers.

"Institution of Gas Engineers congratulates Institution of Electrical Engineers on attainment of Jubilee and sends best wishes for future."—THOMAS HARDIE, *President.*

From Mr. Thomas A. Edison.

"I send hearty congratulations to Institution of Electrical Engineers on its jubilee anniversary. May its useful existence be continued without limit."

From Sir John Snell (Chairman, Electricity Commission).

"Electricity Commissioners wish success to Jubilee Celebrations. Much regret their unavoidable absence."

From Sir John Snell (Past President, I.E.E.).

"All success to jubilee celebrations. Profoundly regret unavoidable absence through office duties. May the Institution flourish."

From Mr. G. Semenza (Local Hon. Secretary and Treasurer for Italy).

"Sorry unable attend celebration. Please convey Institution and all good friends expression my sincere feelings."

From Mr. Henry Edmunds.

"Regret unavoidable absence on Institution's fiftieth anniversary. May the next fifty years complete a centenary of electrical progress; greatly benefiting humanity; distributing power, light and intelligence; making for peace and prosperity, with goodwill among all nations."

The Right Hon. F. G. Kellaway, P.C., M.P. (Postmaster-General) in proposing the toast of "The Institution of Electrical Engineers" said: I appreciate the honour you have paid me in asking me to propose this toast, and perhaps it is not altogether unfitting that the head of the British Post Office should be given this honour, for during the 50 years that your Institution, in one form or another, has been in existence, the relations between it and the General Post Office have necessarily been close and have always been friendly. I am glad, as the head of the Post Office, to have the opportunity of proposing this toast and of congratulating you on 50 years of very remarkable work. You began as a body of about a hundred men, calling yourselves the Society of Telegraph Engineers. In the short period of time which has elapsed since then, short as it is in the history of a nation and of an industry, you have seen the science and the art and the industry with which you are associated make some of the most remarkable developments in the whole history of human endeavour. When your Society was established 50 years ago, the only branch of the electrical industry which was then flourishing was that of telegraphy. Nothing was known about telephony; nothing was known of its most modern, its most romantic and its most baffling manifestation, wireless telegraphy and wireless telephony. In that period you have seen, in association with your industry and your art, developments that have revolutionized the conditions under which modern society exists, and your Institution has played a great part in the rapidity and the efficiency with which those changes have been made. From a hundred members you have grown to an Institution of 10 000 members, with a Royal Charter and the great honour of having His Majesty the King as your Patron. No man in those early days, however audacious his imagination, could have foreseen the changes which this period of 50 years has produced. It was only in 1874, a period within the memory of most of us, that the first efforts were made which resulted in the invention of the telephone, and so recently as 1879 the first public telephone exchange was opened in Coleman-street. It is only a quarter of a century since Marconi came to this country and, in conjunction with the General Post Office, made his first tentative experiments, conducted on the roof of one of the Post Office buildings. He succeeded in effecting communication between that building and what is now one of our telephone exchanges in Carter-lane, and the officials of the Post Office have told me of the enthusiasm which that modest but successful experiment aroused in the minds of the men who were there with Marconi. To-day, in rather less than 25 years, that modest communication of a few hundred yards has been extended until we are able, from the Marconi station at Carnarvon or the Post Office station at Leafield, to get into communication with the furthest ends of the earth. There is nothing in romance which equals so marvellous an accomplishment as that. I had on my desk this morning a letter telling me that from our station at Leafield (comparatively, i.e. compared with what we hope to do, an old station) we had been able to communicate with vessels of the Orient line sailing round the coast of Australia, and that communication was kept up except under the worst possible conditions. When such advances as those have been made in 25 years, who shall place any limit to the possibilities of the science and the art in which you are engaged? But what we, I think, as men of our race have a right to be proud of is that this industry, science, and art of electricity has had its greatest contributions from men of our race. Faraday and Kelvin and Wheatstone and Bell, these are names which for all time will be associated with the development of this great art. I think that if I would compare your work with that of a politician you have the more excellent part to play. In these days, when political institutions are changing from hour to hour, when the very fabric of society is being challenged over great parts of the face of the earth, I find an abiding sense of strength and security for the future in the

fact that, however much political institutions may change and the boundaries of nations may be altered, still the work of scientific development, of research and of inquiry goes on, producing results which are adding to the sum of human happiness. I find an abiding sense of strength also in the consciousness that your work goes on, however much these things in which we politicians are concerned may change from day to day. You are bringing home to the whole world the fact that we are one great family, members one of another, and the politician's task in relation to your activities is to see that your energies and your genius are set free to develop themselves under the most favourable conditions. I conclude what I have to say by trying to give expression to the pride I feel in the part that British audacity and British ingenuity have played in the development of this most modern of sciences and of arts. This race of ours—we British people—is not usually associated either with audacity or with suppleness. This development which some of you have watched for half a century, proves that these qualities are not foreign to our race, for where has been shown, in any country or in any industry, greater ingenuity, greater audacity or greater enterprise than has been shown in the development in which this Institution has played so great a part? We are credited throughout the world with having secured the position we occupy in the world by a certain elemental strength; but British audacity and British ingenuity are qualities which have made our race what it is, and which your industry has proved are qualities that are as acute and as active as ever. Two hundred and fifty years ago a great master of English prose, speaking of the English people and addressing Parliament, said: "Lords and Commons of England, consider what nation it is whereof ye are and whereof ye are the governors; a people not slow and dull, but of a quick, ingenious and searching spirit, acute to invent, subtle, and in any discourse not below the reach of any point, the highest that human capacity can soar to." I say to the members of this Institution, speaking of what I know and what I saw during the war, and speaking from my heart, that those qualities have been displayed in bad times and in good times, by those who have practised this great industry, with a vividness as great as ever in the history of this country, and it is with pride that I ask you to join with me in drinking the toast of "The Institution of Electrical Engineers."

The Chairman (Dr. W. H. Eccles), in responding, said: I wish I could command the felicitous phrases and the happy allusions to match the admirable speech of the proposer of this toast, but it is obvious that the statesman cannot be rivalled by the technical man on his own ground, and therefore I shall ask him to accept sincerity of expression instead of flowers of rhetoric. This week is a great week for us. It is the commemoration of the fiftieth anniversary of the first meeting of the Society of Telegraph Engineers, and this is also the first Dinner we have had since the granting of the Royal Charter and since the King became our Patron. I think that if our President had been here to-night he would have referred at length to the granting of the Charter, and especially to the share that our immediate Past President, Mr. Atkinson, had in the negotiations and in working out the details. I should like now, on behalf of the President, to express the gratitude of the Institution to Mr. Atkinson for the energy and skill with which he accomplished that task, and for the speed with which he did it. The Postmaster-General has referred to the remarkable growth of the Institution in the 50 years of its existence. We began with 110 members, and at present we number over 10 000. We are, in fact, the largest professional engineering institution in the country. There must be some reason for this. I think the immediate and practical reason lies in the fact that electrical engineering has applications more variegated than any other kind of engineering; it reaches into almost every household, into every corner of the country, every stratum of the community. Its amazing flexibility and adaptibility are based on the fact that electricity is more fundamental than matter, or perhaps even than motion, and therefore electrical engineering must necessarily, as science develops, become more and more important and must inevitably play a greater and greater part in the life of the State and the community generally. One might say without exaggeration that at the present day the mightiest and the most obedient machines are electrical. If we want to produce light on the scale of the tens of millions of candle-power that are required to-day the electrical method is the only way. If we want to reach very high temperatures, either in practical furnaces or in laboratories, we must use electricity; if we want to communicate from one end of the earth to the other by cable or by wireless we immediately invoke the aid of electricity; if we wish to convey our voices into any room, any street, or any business office of a large city, we again make use of electricity in the network of wires that run through our telephone exchanges (which we grumble at so often because we do not grasp its complexity). Obviously, this enormous development of electrical engineering must have its effect on the State. To look at it from only one aspect, electricity has practically become, one might say, the life-blood of the community, and if, for instance, any disgruntled section wishes to destroy the State or seeks to hold the State up to ransom, the first thing it aims at is to cut the arteries, veins and nerves of the electric power and lighting systems and means of communication. I mention this only to emphasize how necessary it is for statesmen to take cognizance of us, and to utilize the Institution more fully than they have done in the past, and to study the requirements and difficulties of the industry more thoroughly. I think that if our President had been here he would have treated us to some comments upon the necessity or the non-necessity of legislation as regards electricity. I myself am not competent to give a lead on that subject, and indeed, if I ventured to deal with it, I might not give an account of the matter which would accord with his views. But I urge that future Governments must take account of the developments of which I have spoken, more especially as affecting control of this new commodity and convenience, and as affecting the problem of public ownership versus great combines.

I think that the bond between statesmen and electrical

engineers ought to be one of considerable sympathy. We both work with invisible and intangible forces, which cannot be weighed or easily made visible; the politican works with the pressure of public opinion and the Press; we on our part work with volts and amperes, electrical forces and magnetic forces, which are just as invisible and intangible and which were less well-known a hundred years ago than the forces the statesman studies and utilizes. That bond of sympathy with us, all statesmen I think will admit, but we on our part must admit that in many ways the statesman is our superior; he can pull wires more adroitly than any wireman; he can see through brick walls, very often, better than X-rays; and he can see into the middle of next week in a way which would baffle all the Einstein doctors. I have known him to steal the other man's thunder; and of course he is now dealing with a human dynamo grinding an economy axe. Finally, we must admit that he wields the most powerful lever known in the world, namely the human jaw, and there we give in to him at once. And now it remains for me to convey to the Postmaster-General our deep gratitude for his address this evening, and to say that we appreciate it all the more because the Post Office was one of the few branches of the State that assisted us in the early days when this Institution was founded. We thank him very much.

Mr. Ll. B. Atkinson, Past President, then proposed the toast of "Our Guests," to which **Air-Marshal Sir H. M. Trenchard, Bart., K.C.B., D.S.O.,** and the **Hon. Mr. Justice Sargant** responded.

A reunion was then held in the Victoria Hall of the Hotel.

WEDNESDAY, 22 FEBRUARY, 1922, AT 3.30 P.M.

(Held in the Institution Lecture Theatre.)

Dr. W. H. Eccles, F.R.S., Vice-President, in the chair.

The Chairman: In opening the meeting to-day I have first of all to express what I am sure is the universal feeling of regret that our President has been stricken by sudden illness and is not able to be with us. If he had been here he would doubtless have delivered from the store of his memory some introductory address dealing in a general way with these Commemoration Meetings; in his absence, however, and without having had an opportunity of preparing such an address—and without, indeed, the experience that he possesses—I propose not to touch on that subject at all, but merely to recommend to everybody present a perusal of the programme. I think we are very fortunate in having Colonel Crompton with us to-day, as he is one of the Homeric heroes of the electrical industry. One feels when one looks at him that he is the Agamemnon of electric lighting and electric power distribution.

[The following addresses were then delivered.]

COLONEL R. E. B. CROMPTON, C.B.

Although we are celebrating the fiftieth year of this Institution my connection with the Electrical Engineers dates back only to 1877. At that time I had purchased a Gramme dynamo, and a Serrin lamp to enable me to work a night shift on my newly designed pipe-moulding pits at the Stanton Iron Works. I necessarily then went to the Telegraph Engineers of the time in order to learn some of the technicalities of their business and I found that these were very wonderful. They then calculated resistance in miles of iron telegraph wire although they sometimes referred with awe to the newly invented Siemens or B.A. unit which eventually became the present ohm. Current was then expressed in Webers and E.M.F. in numbers of Daniell cells; the most puzzling thing to us, however, was that we were informed, no doubt on account of their experience of various forms of batteries, that all sources of electrical energy should have their internal resistance duly proportioned to the external resistance of the circuit, and that this applied to dynamos and magnetos quite as much as to batteries. Preece himself used to tell me that if we reduced the internal resistance of our dynamo armatures below one-half of the total resistance of the circuit, including the lamps, we should work inefficiently.

In 1878 I began to be credited with electrical knowledge which I could not fairly claim, simply because I went to Paris with a party of the Institution of Mechanical Engineers and there took part in the discussion which followed on a paper read by Hippolyte Fontaine on "Electric Lighting." It appeared that I was the only English mechanical engineer who had worked with a dynamo and also spoke French, so that I was at once acclaimed in France as the English electrical engineer. Undoubtedly this brought me business and I received many orders to carry out electric arc-lighting in England and Scotland.

My early experience was rather that of a showman going round the country with portable electric light apparatus to show what it could do and thus get orders. Our experiences were very amusing and we had many adventures, notably when lighting Henley Regatta in the evenings. We had a free fight with some of the crews of the boats who thought it a great lark to cut our cables. These we defended, and by the judicious use of the spanner we secured our circuits from interruption.

In 1879 I was introduced by Brown of Winthertur, the father of Charles Brown of Brown, Boveri and Company, to Emil Bürgin of Basle in Switzerland. Bürgin had designed a new form of dynamo which undoubtedly was far better from a mechanical engineer's point of view than the Gramme machine of that time. The Gramme dynamo that we then purchased in France was a poor mechanical job. The wound armature was mounted on a wooden hub, pressed on to the spindle,

which was difficult to balance and keep in position. The iron core of the armature was of small section, and, no doubt in order to obtain the much desired internal resistance, the armature winding was composed of a great number of coils of fine wire. Bürgin's design is well known to those present but it undoubtedly interested me in that it laid the foundation of the Crompton firm. We were soon turning out his machines in quantity at the Chelmsford Works, and as we got good prices and always sold two or three Crompton arc lamps with each dynamo, I soon got money together to enlarge the Works and took on my first skilled manager, Gisbert Kapp, who up to that point had been trained as a mechanical engineer at Hornsby's of Grantham.

One day a man came into my office and said in a mysterious manner: "I am ordered to take you off to Newcastle on important business." I was whisked off to Newcastle that afternoon and there introduced to Mr. Joseph Swan who showed me a row of Swan carbon-filament lamps lighted by a Gramme dynamo. Swan had sent for me because I had already supplied him with arc lamps. I then arranged to work together with him and exhibited his lamps at an Exhibition held in Glasgow which showed the latest form of gas lighting and also electric lighting. I think that this was the first exhibition in public of the Swan carbon-filament lamp. We heard at that time that Edison had been experimenting with platinum filaments and eventually with carbon filaments, but our Glasgow Exhibition showed that the Swan lamp was practicable, and I got orders to install these lamps in the Glasgow Post Office and the goods yard of the Queens-street station, and elsewhere. Lord Kelvin, who was then Sir William Thomson, took great interest in our work. He was frequentiy with us, helping us both in designs and with valuable suggestions, and I could recount many stories of his nervous excitement when we found out anything new, which in those days occurred very frequently. I also met James Thomson his brother, Rankine, Professor Jamieson and others, who were very keen to help me with ideas.

About this time I think it was Henry Edmunds who first brought over the Brush and Thomson-Houston system of lighting by arc lamps in series. This attracted great attention and many local companies were formed under the parent company. This system of lighting was to revolutionize not only external but also internal lighting, and depressed the shares of gas companies quite improperly, as the 1 000-c.p. arc lamps were suitable for internal lighting in only a few cases, and it was Swan's invention, followed by Edison's developments in America, which was the origin of electric lighting as we now know it.

Swan went on quietly with the manufacture of his lamps at Newcastle and a great Company was founded in London by Cuthbert Quilter, which afterwards amalgamated with the Edison interests to form the Edison–Swan Company. This latter Company took over from my firm a great deal of the installation work which we had already in hand, and which even at that early period, 1882, was sufficiently advanced to enable me to secure an order for the lighting of the newly constructed Law Courts.

So far as I remember, the first private house that I saw lighted was my own at 23, Porchester-gardens, in 1881. This I first carried out with small inverted arc lamps, shortly afterwards replaced by Swan lamps, and this private installation worked so well that it got me orders for lighting country houses, and a few town houses where there was room for a gas engine to be installed in the cellar, and where the neighbours did not object to the noise. Berechurch Hall in the country was quickly followed by Lord Randolph Churchill's house at Connaught-place, Sir William Gilbert's house in Harrington-gardens, and Sir Joseph Crooke's house in Kensington-park-gardens—all in 1884. The installations in all cases were almost identical, a 3½-h.p. Crossley gas engine and a Bürgin dynamo with a heavy steel flywheel which used to run at 1 600 revolutions, with E.P.S. accumulators in parallel.

The installation at the Law Courts completed by Cromptons in 1883 was of considerable size. It commenced, I think, with not less than 1 600 lamps installed, and in it we introduced most of the appliances now in use, such as switches, pendants, brackets, plugs and portable lamps, all of which were designed almost in their present form by my then partner Harold Lyon Thomson.

The Electrical Exhibition in Paris in 1881, and that at the Crystal Palace in 1882, undoubtedly did much to call the attention of the public to the advantages of electric light, and I well remember explaining the system of the electric circuit to Queen Alexandra, and showing her that a 200-volt contact shock was merely disagreeable, but not dangerous. Even up to that time, however, the public thought quite as much of arc lighting as they did of Swan lamps, and our inventive powers were devoted as much to the one as to the other.

As I had long known P. W. Willans I should like to put on record how much we, the electrical engineers who were pressing forward the work of distributing electricity, owed to the great knowledge and prevision of Willans. At an early date Willans supplied me with his high-speed engines which could be coupled directly to the armature shaft of our dynamos. At that time we had got well away from the early Gramme or Siemens dynamos and, although I did not know it, Hopkinson was working at the general improvement of the Edison form of dynamo, whereas I was trying to do the same for the Gramme ring form.

During the early days we were haunted by Preece's ideas of the necessity of having many turns of wire on the armature in order to obtain the necessary internal resistance to deal with large external resistances in our circuits. In our many talks with Lord Kelvin, Willans and I thought that this necessity for internal resistance did not exist, and, wishing to know something of what Faraday had shown as to the effect of moving a coil of wire in a magnetic field, the idea naturally occurred to us, as mechanical engineers, that we ought to improve the magnetic field.

In those days we used to talk a great deal about lines of force. Kapp went so far as to call them Kapp lines; we had, however, the vaguest ideas on the relation of the strength of our magnetic field to the power generating electromotive force in our armatures, and

it became absolutely necessary to get mathematical data to work on. To get this I myself travelled many miles between London, Edinburgh and Glasgow, pointing out to Sir William Thomson and to Rankine that it was imperative to have a formula for our electromotive force, and we eventually found that it was proportional to $4\pi \times$ ampere-turns divided by twice the air-gap.

Having seized on this I went back to my own designer (Kapp) and told him we must cut down the air-gap. "Oh," he said, "you will diminish the space needed to get the necessary number of turns on the armature, and you will not get the electromotive force you require." I urged that if we made our magnets and our armature cores of largely increased cross-section we should get such an improved magnetic field that one layer of winding on the armature would give us the E.M.F. we required. But Kapp would have none of it. Luckily, Kapp's holiday was then due and during his absence I made a dynamo with huge field magnets of Swedish iron, with a huge armature core-ring of soft-iron plates pushed on to spiders and with only one layer of armature winding, so that the air-gap on which so much depended was reduced in this machine to a little over $\frac{1}{8}$ in. on each side, the double air-gap being thus only $\frac{1}{4}$ in. This machine was finished and on the bed-plate when Kapp returned. When the test commenced, owing to the fact that the large mass of iron had but little residual magnetism the magnetic field took some time to build up, so that at first there was only a very small E.M.F. in the circuit. Kapp said quite triumphantly, "I told you so, you have wasted your money; you have nobody but yourself to thank." But even as he spoke the field began to build up and the E.M.F. mounted rapidly, the testing resistance became red hot and the belt came off; but the modern dynamo was born. I only knew later from what Hopkinson himself told me and from what Wordingham will tell those present here, that Hopkinson had been working on identically the same lines as I had, neither of us knowing what the other was doing. I showed a dynamo of the new form at the Inventions Exhibition and the judges gave me a Gold Medal.

My first partner, Harold Thomson, was the inventor or designer of most of the common appliances that we now use, as nearly all the switches, plug contacts, fuse arrangements, the general arrangement of switch-boards, the suspension of lamps by their own flexibles, were worked out by him and by Mr. Lundberg, who I see is here present, and who, as his son informs me, is 91 years old. I am sure you will all join with me in congratulating Mr. Lundberg on looking so well and so young. His presence is a sign, I think, that there is hope for all of us, for it shows that the electrical profession, in spite of all its anxieties, does lead to longevity.

Soon after the Law Courts installation was completed I went out to Vienna to work out for the Imperial Continental Gas Company a large installation of electric light for the supply of the Imperial theatres from a central station in the Schenkenstrasse, since, owing to a disastrous fire at the Ring Theatre, where many lives were lost and which was due to an escape of gas, the Emperor desired the Gas Company to supply electric light on a larger scale than up to that time had been attempted. In the design of this station, which I carried out jointly with a French engineer, Monier, I was greatly aided by Willans, for he there developed with me the design for high-speed direct-driven dynamo sets which we used in the majority of d.c. installations for many years afterwards.

The Vienna scheme was remarkable in that we had to supply 20 000 lamps in theatres $\frac{3}{4}$ mile from the central station. We used a 5-wire system, with about 500 volts across the dynamo terminals, the distribution being by four large batteries of accumulators coupled between the five wires. The Willans engines were of 200 h.p. each and were electrically governed.

Our proceedings at Vienna were closely watched by Messrs. Rathenau and Deutsch, who were then engaged on a central station in Berlin. They frequently came to see us, and their endeavours to copy our compact direct-driven sets were positively comic: they used low-speed engines of the marine type made by Van der Kerchove of Ghent. In order to drive these direct they were obliged to mount huge Gramme rings on a prolongation of the engine crankshaft and use a star-shaped internal magnet. Their arrangements occupied about ten times the cubic space of the Willans–Crompton sets, and the economy obtained, especially at low loads, was not nearly as good as we obtained.

As our work at Vienna extended to those installations at the Grand Opera and other theatres we had to devise, for the first time, most of the electric appliances which are still in use in theatres. Monier and I worked out convenient methods of indicating the current in our feeders by measuring the fall of potential on a portion of our busbars, by using a delicate D'Arsonval galvonometer with magnetic control: in this way we were able to measure currents up to several thousand amperes within 1 per cent.

During the progress of the Vienna work, which went on from 1884 to 1887, we attempted to commence house-to-house lighting in London, but found it very difficult to raise capital under the terms of the original Chamberlain Act. At Kensington-court, however, I found a subway through which I was able to lay at a low cost sufficient bare copper mains strained over porcelain insulators to supply nearly 100 houses. I find on reference to one of my old report books, that on the 7th October, 1886, the work was well advanced and the supply was about to commence. At Kensington-court we developed further the system commenced at Vienna, but used a 3-wire instead of a 5-wire system, with accumulators in parallel with the Willans sets.

I find that our success in showing that electricity could be produced with certainty at a low cost attracted the attention of prominent financial firms, and from that time the difficulty in getting together capital diminished.

During 1886–1887 a very brilliant young man appeared on the scene: Ferranti. He took up the a.c. transformer method of distribution and soon he and I became the captains of two opposed schools of electric distribution. At the time I was starting at Kensington-court and canvassing householders to take the electric light, Ferranti, with Lord Crawford, started the Grosvenor

Gallery and many interesting things occurred. As I at Kensington-court always had accumulators in reserve I never had any extinctions or stoppage of the light, whereas the difficulties with alternating currents, which no doubt Ferranti will describe to you, caused many extinctions at the Grosvenor Gallery. I could tell many amusing stories of the horror of chaperones when Mayfair ball-rooms were suddenly plunged into darkness, and it can be realized how difficult it became for me to preach safety and continuity of electric supply at Kensington when such proceedings went on in Mayfair.

But soon the battle-ground was shifted to the theatre of the Institution and many of those present will remember the many long and interesting debates which took place as to the comparative merits of the d.c. and a.c. systems. I believe these debates had the very desirable effect of calling attention to the very interesting nature of our profession and brought in many recruits from the young mechanical engineers of the day.

In May 1883 we, the electrical fighters of the time, started a dining society so as to be able to meet, and discuss in peace, matters other than those electrical. We christened this the "Dynamicables" and by August of that year we had 100 members; and during the following 5 years every electrical man of note joined us, so that by 1888 our members rose to about 250. At our dinners at the Aquarium we forgot all about the business worries of the day, and many lasting and pleasant friendships were then made. A curious thing was that one of our members, proposed by me and duly elected, turned out, when he died a few years after, to be a woman. I daresay many of those present will recollect the extraordinary trousers that he (she) wore. At the Dynamicables we discussed many interesting problems and were decidedly the first to take up those problems which Professor Huxley dealt with a few weeks ago at the Society of Arts.

I owe to Professor J. A. Fleming many useful ideas, the potentiometer amongst them. Some among those present may remember the very simple form in which he showed us how to make up the accurate low resistances we required to measure currents by the fall-of-potential method. The assistants in my laboratory were then Fisher and Sidney Melsom, who is now at the National Physical Laboratory. They will remember the interesting time we had in perfecting the potentiometer sufficiently to enable us to make measurements of current and E.M.F. correctly to four places of decimals, and this refinement in electrical measurements was usefully applied at Willans's works at Thames Ditton. Many will also recollect the interesting competitions between rival dynamo-makers when their dynamos were coupled to Willans's engines and tested under identical conditions at the test beds at the Willans works. At these competitive trials the unexpected efficiency shown between the indicated horse-power of the steam engine and the actual electrical output at the dynamo terminals put us English engineers for quite a considerable time in advance of any nation in the world in this high efficiency of transformation. We at that time used manganin as a standard material for low resistances for the above purposes.

When we began to lay mains in the streets of London we made our first start in the Kensington-court subway by using bare copper conductors stretched over porcelain insulators. This led to our constructing many miles of subways under the foot pavements of the West End, and although cable-makers shook their heads and prophesied all manner of disasters if I went on with such a mad procedure as laying bare copper underground, after 40 years these conductors are still in use and in good order and will probably outlast most of us; but we did have minor troubles arising from their use. We found that the gas companies not only supplied it to the house, but, through leakage from their pipe joints and surrounding soil, to our culverts, in which gas frequently accumulated; and when this gas was accidentally exploded the covers of our surface boxes were blown into the air and were the cause of public anxiety. How the gas was ignited was never solved, but I think that then, as now, the smoker and his matches had something to do with it.

From the very earliest period electric meters were an interesting matter to the supply companies. In this matter Ferranti again helped us by some of his very beautiful designs; but it is rather disappointing that, although we have had the bright example of the gas companies before us for so many years, we have never yet been able to come up to their commercial standard of putting in meters which register up to 20 or 30 per cent against the customers at low loads: we poor electrical men have always had to be content with under-registration when the load is small.

Some of those present may recollect the very interesting trial, Harness *v. The Electrical Review*. The *Electrical Review* had very properly said that Harness electropathic belts were really a fraud and contained no source of electrical energy. My laboratory staff will recollect the very interesting time when we made Mr. Alabaster's body into a living standard resistance and attempted to obtain from the Harness belts sufficient E.M.F. to get a deflection on my reflecting instruments. These tests, at which Lord Kelvin was present, were amusing and interesting to everyone except Mr. Alabaster himself; but, largely due to them, Alabaster and Gatehouse won their case.

SIR ALEXANDER KENNEDY, F.R.S.

Before I say anything about the history of the Westminster electricity undertaking I should like to say a few words about my old friend, Colonel Crompton. In the days when I forsook marine engineering and professorial work for electrical engineering, there was no man who helped us on more than he did. Whatever he found out, whatever good work he heard of, he put at the service of the rest of us, which was much more than most other people did. We were all very much indebted to him at that time, and we have often been much indebted to him since.

I should like to give a few reminiscences of the time

when the supply of electricity started in Westminster. The present Westminster Company's undertaking started at a small shanty in Dacre-street and another in Chapel-street, with some "G.G." engines in the Stoneyard of the Houses of Parliament, which were used specially to supply the Houses of Parliament. Their supply was started in February 1890, and Punch's cartoon about Miss Electricity appeared about a year afterwards. I have a letter here which will show how careful we were and on what a large scale we were doing things. It is written by me and dated February, 1890, being addressed to one of my assistants: "The Speaker of the House of Commons has a dinner this evening, and after the House has risen some 30 lamps will be required from dinner time to late in the evening. It will be necessary that either Walker or yourself should be in the battery room until the Speaker's dinner is over. It is of very great importance to see that the light should be especially steady to-night."

Some years before that time I was speaking to a very distinguished physicist on a subject to which Colonel Crompton has alluded. At that time the question was whether anything but arc lighting was feasible electrically. The question I asked him in my ignorance was: "Do you think electric light will ever be able to be subdivided?" "Subdivision" was the phrase which was adopted for working in parallel. My friend said that he did not know, and was certainly not at all sure about it. This was only a very short time before Colonel Crompton's visit to Swan in Newcastle of which he has told us, where for the first time he saw lamps in parallel. In the minds of the most distinguished physicists at the time it was obviously very doubtful whether any such "subdivision" was practicable.

The sort of scale we started on may be understood when I say that I find from my note-book that in the first quarter of 1891 our total income was about £2 600. That was the time, of course, when we were fighting Ferranti continuously. Happily, Ferranti and I are very old friends. I have no notes at all, however, about any fighting, except of a remark I found this morning in a book dated 1890, to the effect that in Millbank-street or the Stoneyard we were using $7\frac{3}{4}$ lb. per kilowatt, "which I believed to be less than one-half the best high tension result"! That is the only trace of controversy I can find in any of my notes.

I think that the chief matter of electrical interest in the Westminster Co.'s history during those years was the great question of whether two stations could be paralleled. I, being only a mechanical engineer, could not see why there should be any difference between paralleling two dynamos a mile apart and two dynamos a few yards apart, but my electrical engineer was very strongly of opinion that it could not be done. He said he had tried it. He was probably confusing alternating current with direct current. Colonel Crompton had two stations at a considerable distance apart which were connected by mains, but he had never coupled the stations up. I asked him why he had not done so, and he said he did not want to. Of course, he knew perfectly well that it could be done, but apparently it had not actually been done. Accordingly, I stood by one of the machines at the Stoneyard and telephoned through to Dacre-street. The date of this exciting experiment was February, 1891. We solemnly switched the two stations into parallel and of course nothing happened! But my engineer, who was beside me, was as much astonished as Mr. Kapp seems to have been on another occasion. These are small matters of history. It is also history that we started to turn the old 2-wire system into a 3-wire system in Westminster in September, 1891, and finished in December of the same year. It is also, perhaps, a matter of history that our early machines were not very large; their capacity was 112 kW each and they cost from £1 700 to £2 300. A short time afterwards I wanted tenders for machines of double that size, and we had very great difficulty in getting them. I think that only two makers in this country were prepared to tender to us for 250-kW dynamos at that date.

Of course we had our troubles; noise and vibration were always present. The first difficulty we had due to these causes was at Millbank. At that time there was a little company called the Westminster Syndicate, which was the predecessor of the present Westminster Company. This Syndicate had ordered for Millbank-street two large semi-portable engines. When I arrived those engines went somewhere else; we certainly never used them. But they were taken one day on to the Millbank-street site, and carefully covered up with tarpaulins. A day or two later we had loud complaints of vibration and noise from the residents in Millbank-street; they said they could not sleep at nights. I let them make a formal complaint, and then I asked them to come in and look at the machines, which had never had the tarpaulins taken off. We did not have any more trouble with them! When we started the Davies-street installation a few years afterwards, Mayfair was very particular about vibration. There was a certain doctor in Brook-street, close to the station, who in the first place insisted that we made smoke. I asked him to tell me when he had seen any smoke. He said he had never seen any, but he knew there must be some, because we had a chimney, and a chimney was constructed for the sole purpose of carrying away smoke! He was very much troubled about vibration also, and we had a little vibratometer made which we sent to his house, with his permission, together with some observers. I went to Davies-street and ran one engine, two engines, no engines and so on at times which were noted. When the two sets of observers met together after two or three hours, some of my observers said: "The only time when there was any considerable vibration was at so-and-so; you can see it on the record." I looked up the time, and it had occurred when the station was entirely shut down! That is to say, the whole vibration had been merely that caused by heavy traffic along the road. Another complaint we had in the same neighbourhood was also from a doctor. It was not very definite, but generally alleged noise of sorts. I called on him, and he asked his housemaid what she knew. She said: "Well, sir, whenever I open the door I hear

the current roaring in the mains underneath the pavement." I had to explain that I did not think the current roared in the mains and the doctor did not proceed further with any legal proceedings. Another case which occurred in Westminster also concerned a doctor. He made a very serious complaint against us, saying that there was something very wrong with our current, because it caused showers of sparks in the incandescent lamps. I could not imagine what he meant, until it dawned on me that the filament must have broken and was shaking about, and this proved to be the case.

I should like to tell one other story, which I heard only this morning. It is not in my records but Mr. Grimshaw reminded me of it, and it is certainly against ourselves. The incident occurred at Millbank-street in the early days. I do not know how many lamps we had on the circuit then, but not any very large number. My engineer of that time, who has gone long ago, fortunately (he was a very unsatisfactory person) was not on the spot. The engine driver broke the hand-wheel off the stop valve of his engine so that it could not be closed, but he said nothing to anyone of what had happened, and sat down peacefully awaiting events. It occurred in the evening, and gradually people began turning out their lights, and naturally the engine, bereft of regulation, began to go faster and faster, and the voltage went up until we burst all the lamps on the circuit. Fortunately there was not a very large number of them, and I believe Mr. Grimshaw and someone else spent next day going through with a basket full of lamps and replacing them.

It is interesting to see the way in which from little beginnings the present very big installations have sprung. It is also very interesting to some of us to know that we, who were fighting in the manner Colonel Crompton has described, are nowadays very good friends. In fact, it may be said that with the introduction of time as a fourth dimension electrical attraction has greatly exceeded electrical repulsion.

SIR OLIVER LODGE, F.R.S.

It was pleasant to hear Colonel Crompton say he was not an old man, because I belong to about the same period. I remember Colonel Crompton and his superabundant energy very well in the days when I was with Carey Foster at University College, London. My subsequent house in Birmingham I found had been lighted by an amateur, Albright, who had been a pupil of Crompton's; and it was said to be the first house in Birmingham that was lighted by electricity. We continued to use that installation, although we could have got on the mains. We continued using our 40-volt system of accumulators and the Crompton dynamo and so on, until I left there about 2 years ago. The wiring, however, would have shocked any of to-day's experts. It did very well for 40 volts, but I dared not go on to 220 volts without complete re-wiring. My gardener looked after the engine and dynamo, and one day, when the lights were getting dim and the engine suspiciously quiet, he told me that he had not lighted the pilot jet (the gas engine had not got a magneto spark but a pilot light), as it was not necessary, since the engine ran just as well without it! Of course it did, because of the accumulators.

I can go back a long way into the days of the Telegraph Engineers. I remember when there was no generally recognized ohm. I have heard 70 feet of ordinary bell wire specified as a kind of unit of resistance. And of course no current was laid on, for long after that. When we wanted to have the spectrum of metals projected on a screen by an electric arc at the University College we had to put up 40 Grove cells each time, and put up with the fumes too. I remember, also, the ampere coming into use, and a workman speaking of it as a "hamper of electricity."

I also remember the introduction of the term "dynamo." I am not sure whether it was the first time the thing was so called, but I rather think it was. I was Secretary of Section A of the British Association at that time, and Lord Kelvin was reading a paper on something about the efficiency of what we then called a dynamo-electric machine. We discriminated between a dynamo-electric machine, which had electro-magnets, and a magneto-electric machine which had permanent magnets. In correcting a proof of the Sectional programme, someone had put his pen through the words "electric machine" in the title of his paper; so I restored them and showed him what had been crossed out. He said, "Well, I did it. I want it to be called dynamo for short." The paper was therefore given as on the efficiency of the dynamo, and he had to explain what he meant by a dynamo. As far as I know, that was the time when the now very familiar name first came in.

At the invitation of Dr. Traill, I went down with FitzGerald to see the first electric railway—Lord Kelvin was there too—which ran between Portrush and Bushmills. The Siemens firm had rigged it up, and the electrical engineer was Edward Hopkinson, who died recently. That Portrush and Bushmills railway was worked by water power from the Bushmills waterfall; and was a very interesting experiment. The electrified rail was about one foot off the ground, on little posts by the side of the railway, and the railway ran by the side of the road. Of course, this rail sometimes went past gates and once it killed a cow. I forget the voltage, but quite a nice, harmless shock could be got from it. There was nothing to prevent people from touching the live rail, and FitzGerald and I amused ourselves by taking these shocks. Lord Kelvin, however, could not feel them at all. He asked us what we were jumping about for. We said, "You try it." He tried it, gravely pressing both hands on the rail. After a pause he remarked, "I think I do feel something." I suppose his skin was so dry that a moderate number of volts had no effect on him. It reminded me of the old charwoman in "Three Men in a Boat." Many will remember

the incident about a cheese, which was so strong that it made the cab-horse gallop when they were taking it away to bury it, and the charwoman said yes, she did notice a something.

Those were the days of the compound dynamo—compound winding of the field magnet. I do not know whether they are compound-wound now: I should think not. At any rate, the one on this railway was compound-wound; and one day something happened at the motor end away down the line, and we got a surge back, a sort of "Ferranti effect," which reversed the field magnet in the power house, giving a great rush of current. Lord Kelvin was anxious to avoid this liability, and tried short-circuiting the series winding of the dynamo. I was helping, and had coiled a bit of string round two flattened copper terminals so that by pulling the string I could short-circuit the series winding, and then let it go again, and so on, while it was running; and Lord Kelvin was giving orders and reading the meters to see if it made any real difference, so as to ascertain whether the series winding was really necessary; because it was the series winding which caused the magnet to be reversed by the opposition surge. It would not have hurt a shunt dynamo; with series winding, however, the current was driven the wrong way, motor and dynamo no longer in opposition, but both helping each other.

I was scientific adviser to the Electrical Power Storage Co. for a time, and that company ran an early electric tramcar. It had storage batteries under the seats. I remember devising a scheme for putting the motors in series for starting and in parallel for running. We went out about six in the morning on a trial trip. The first day was a failure, because the car ran out of the yard too vigorously and refused to take the bend into the road. It did not stop, but went straight across the pavement towards a shop window opposite. The test had to be put off for another day. Next day it took the bend all right, and when travelling placidly along the road we met a milk-cart in the early morning. It was very interesting to see the intelligence of the animal in the shafts of the milk-cart. The tramcar looked like any other tramcar; it was making no more noise than any other tramcar, and there were lots of horse tramcars in the neighbourhood. But this one had no visible means of propulsion, and the horse noticed it. The horse looked at it, looked again to see what was pulling it, and then began backing away; it knew the car ought not to be able to go like that without a horse.

Resistance units, current units, and voltage units all came in gradually; but it took a little time and a little consideration to get the idea of self-induction into the minds of the early workers, especially those in the telegraph service. I remember Sir William Preece speaking of it publicly at the Bath meeting of the British Association in 1888 as "a bug," what the Americans call a bugaboo, a kind of thing that is a perfect nuisance. He was annoyed with Mr. Oliver Heaviside for emphasizing the importance of self-induction in cables. I think that the work of Mr. Heaviside has perhaps not received quite its due share of recognition. Lord Kelvin gave the first theory of cables, and made the first cables electrically possible; at any rate he made them much more satisfactory than they otherwise would have been, by his theory of diffusion, like thermal diffusion, which took into account capacity and resistance. He did not attempt to take self-induction and true wave-propagation into account. Mr. Heaviside did, and gave the complete theory, showing that whereas resistance and capacity together were deleterious and distorted the signals—because different frequencies travelled at different rates and came out mixed, so that speech through a long cable was impossible, and ordinary signals were smoothed out and liable to be greatly confused—the effect of self-induction would be to preserve distinct features. It would partly neutralize the effect of capacity. Hence by loading the cable, introducing self-induction on purpose, one could reduce the damage done by capacity and resistance. Everyone knows that loaded cables are now used for telephonic purposes. I believe a great deal more could be done by suitably introducing self-induction in cables. Experiments have been going on for a long time on that subject at Electra House, and I think the speed of signalling may yet be considerably increased.

Mr. Heaviside is still with us, living in Devonshire, and I have been told he is in bad health. I think that at this fiftieth anniversary of the Telegraph Engineers it would not be improper to suggest that a message be sent to him expressing our recognition of the mathematical work—the brilliant mathematical work—which he did, and which appeared for many years in the *Electrician* and was reprinted in his books. His work was in advance of his time, but it has borne practical fruit in the hands of practical men. Mr. Heaviside was a genius of a very extraordinary type. With the permission of the Chairman, we might send him a message from the meeting assembled on this auspicious occasion.

MR. E. GARCKE.

A Broad View of Electricity.

When I contemplate the hundreds of millions of capital invested, the hundreds of thousands of persons employed in our industry and the undoubted fact that the amenities of the social state are largely dependent upon electrical machinery expressive of some *thing* or some *activity* we are unable to define, I confess to an uncomfortable feeling. As a director of electrical undertakings I ought to know what it is we are busy with. Such an inquiry leads us, however, beyond even the sphere of theoretical science into the realm of speculative thought. One authority says that electricity is neither matter nor energy; another says that we

should speak not of electricity but of electrification. In spite of the existing uncertainty about ultimate things, electrical science, probably more than any other science, represents a beautiful sequence of facts and deductions—the result of years of observation and of the union of theory and practice. If George Eliot was right in saying that " there is nothing petty to the mind that has a large vision of relations," the electrical engineer may be expected to develop exceptionally large views ; for if he thinks about his subject philosophically he cannot fail to recognize that the phenomena of electricity are fundamental not only to physics and chemistry, but also to biology and psychology. It is not easy, however, even for those who are engaged in the industry, to trace the labyrinthine paths of theories, technologies, industries and services, bounded on one side by difficulties of research, on the other by those of finance, and obstructed at many points by political entanglements. But the general public are interested in the utilitarian fruits of these events rather than in the mechanical, intellectual and social processes by which they have been developed.

In order to locate the starting point of the present electric supply industry, it is necessary to imagine a threshold between cosmic nature and industrial arts. For electricity was not invented by man, the voluminous records of the Patent Office notwithstanding. It was never " in its infancy " ; and it is older than is taught in many text-books. We know more about the laws of electricity than we do about the probabilities upon which these and other man-made laws are based

How comes it, then, that this industry has been cabined, cribbed, confined within such narrow boundaries ? The real causes are not now distinctly visible. Electric supply is generally said to date from the Electric Lighting Act, 1882, forty years ago, but that Act was based on the Tramways Act, 1870, and to understand the earlier measure we must go back about 100 years. Such a glance into history is not without interest at the present time ; it shows the rhythm of events and is helpful in framing conceptions of the future.

After the Napoleonic wars, the prevailing distress necessitated the stimulation of industries. The extension of public utilities by private enterprise was therefore encouraged. The subsequent prosperity led to the accumulation of great wealth. At the same time, impetus was given to the development of local government. The telegraphs were taken over by the Government on the basis of estimates which were subsequently found to be too optimistic. The concessions granted to gas and water companies, when brought under review, were found to be not sufficiently protective of the interests of the community. When horse tramways were promoted these views were given statutory expression in the Tramways Act, which marked the legislative beginning of the troubles of the electrical industry. The Tramways Act was not, however, intended to have the effect which it eventually produced. It contemplated municipal ownership, but not the operation of tramways by municipalities. This extension of municipal functions took place later and completely altered the relations between local government and private enterprise. When a few years afterwards powers to supply electric light were applied for, the precedent of the Tramways Act was followed. Joseph Chamberlain, who was then President of the Board of Trade, was a strong advocate of municipal enterprise, and the Act was framed accordingly. In these surroundings the pernicious Act of 1882 was conceived. Politicians were stupid in their legislation, but can we say that scientists were wise in their outlook ? After all, we must recognize that the political conscience embodied in Acts of Parliament forms part of the organized common sense of the time. The basic trouble of the electrical supply industry was that we had to open streets to lay conductors. This necessitated a bargain with the community ; and the bargain was made in the narrow terms of the knowledge then existing. It is interesting to speculate whether the political attitude and the scientific development would have been different if we had at that time been able to think more in terms of electromagnetic waves, and less in terms of underground or overhead conductors. We should at any rate have been spared discussions as to whether the economic radius of distribution from a " central station " was $\frac{1}{2}$ mile or 1 mile. Unfortunately, it is easier to pass an Act of Parliament on a wave of popular impulse than to repeal or amend it. The Electric Lighting Act, 1882, was not amended till 1888, and then only imperfectly. The Tramways Act, which was passed to sanction horse and steam tramways, was obviously unsuited to the development of electric traction, and when in 1896 Parliament was urged to give facilities for the adoption of electricity on tramways, we were told that the Tramways Act could not be amended, but that a Light Railways Act would be passed enabling electric tramways to be undertaken without municipal veto, without limitation of tenure and without purchase clause. This prospect of liberal legislation was alluring but it was never realized. Tramway undertakers were described as having been too astute in using the Light Railways Act for the promotion of tramways. The Light Railways Act was at once interpreted in the terms of the Tramways Act, and tramway undertakers were soon sadder and much wiser than when they put their trust in the promise of new legislation.

The story of electrical legislation has been told many times and in different ways. My articles in *The Times* in 1906, since reprinted, were a trumpet-call for action, while those in the *Encylopædia Britannica* give statistical summaries. But probably the best general descriptive statement of the combined technical and legislative aspects of the pre-war period is contained in Mr. Campbell Swinton's address to the Royal Institution in 1912. For post-war statements of the position we cannot do better than turn to the official reports of the Parliamentary and Departmental Committees. Never before have we been so well supplied with authentic industrial data as now. Every avenue of inquiry has been explored, and the general conclusion to be drawn from the reports is that, notwithstanding the efficiency of British methods and means in attaining practical ends, there is an all-round lack of co-ordination. Than is why I emphasize my remarks in the direction of at appeal for a larger outlook.

What of the future? The larger the view we are able to take of our own interests the better is our understanding of the possibilities of melioration. Society has its structures and functions which normally are complementary, each to the other. But we frequently observe that the structure is not equal to the function undertaken, and that the function in turn lags behind the structure. When these discrepant relations are accentuated, pathological conditions arise and find expression in strife and unrest. Evolution then calls for readjustment; diagnosis suggests recuperation and restoration of normal relations on a new level, generally of higher consciousness. In the present condition of the world it appears that *international* arrangements are necessary for the stabilization of currencies, for the rehabilitation of confidence and credit, for the better distribution of raw materials, and for intensive production. But international arrangements are just the kind of functions for which the *national* structures are not yet developed. I remember the time when competition was on the principle of each for himself; it was a long time before we recognized the economic wisdom of standardization, even in such small things as switches, plugs and lamps. Now we have associations for practically every department of the industry to secure united action where collective interests are involved, and this Institution, no longer content with the view that its duties are confined to discussion of technical matters, acting on a broader policy of providing collective representation for all sections of the industry, is accelerating the advance of science, technic and commerce. Thus equipped, electricity, however we may define it, may be expected to play an important part in the building-up of the nation's welfare. The official attempts to enlarge our ideas have been ludicrous. I could never understand the economic reasoning which, by the Act of 1882, prohibited the undertaker specifying the "burner" (as the lamp was then called) and which insisted—even after the amending Act of 1888—upon each area of supply in London having competing systems of supply, in the supposed interests of consumers. But are we quite sure that in trying to bring producers and consumers into joint council we are not again straining the industrial organization of human nature?

The supreme need of the nation in the present crisis, apart from the international arrangements I have referred to as difficult of attainment, is in the form of better or more sympathetic all-round co-ordination. What is not sufficiently urged is the value of better correlation between scientific research and philosophic generalization. We collect more and more facts, but we fail to combine them into coherent bodies of thought; thus we sacrifice in a large measure the increasing return from combined economy, bulk production and rapid distribution. The all-important questions are: What can be done to hasten the work of rehabilitation? How can electricity help? The Ministry of Reconstruction two years ago gave us a lead. "The public mind," it said, "has been prepared for a large development of electric power supply which will conserve our coal as well as our human resources. Power and transport are the fundamental agencies of modern economic life. An adequate and cheap power supply, widely distributed throughout the country, will open up possibilities comparable with those of the industrial revolution a century ago." In order to realize the full advantage of our opportunity, it is necessary to take a wide view of the problem not only in its economic and social aspects, but also in all the other directions in which electricity is capable of benefiting the human race. Nothing is better calculated to foster this larger view than the present policy of the Institution to bring together the electrical industry and its ever-widening environment.

MR. S. EVERSHED.

Some Reminiscences of Early Days.

The older members of the Institution who are recalling their experiences of early days, are able for the most part to speak with the authority of men who themselves took an active part in the development of our great industry. I, too, remember those far-off days, but forty years ago my work lay almost entirely outside the electrical field and I cannot claim to have been much more than a spectator: a spectator, however, who knew a little about electricity and was keenly interested in what was going on.

Would that I had the power to recall the wonderful vision of a strange new world of electricity, that was so rapidly unfolding itself in the 'seventies and 'eighties. Anyone who lived in those times must be able to remember something of the wonder with which he first saw a dynamo at work, or heard a telephone speak. I am going to relate three incidents of that kind, each of which has left an indelible impression. I shall ignore chronological sequence and begin with what, in early days, was always called *the* electric light. It seemed appropriate to speak of it in the singular, because we seldom saw more than one arc lamp at a time; and what a great blaze of light it was to people who only knew the dingy gas lights in the street. But it was obviously impossible to have one's house illuminated with arc lamps, and a strenuous search went on for some means by which that monstrous blaze of light might be divided into more manageable units. Everybody talked about it. The daily Press knew all about it, and the general expectation was that sooner or later the problem would be solved. Of course the great need was for smaller units of light, better fitted for general use than the arc lamp; and that is what we meant when we talked about dividing the electric light.

Well then, I remember one day reading an excited cablegram from America announcing that Mr. Edison, the great inventor, had succeeded in "dividing the electric light." So far as I remember he did it by means of an incandescent platinum lamp. Then a little later I read an account of an interview given by Edison to some ecstatic American reporter, from which it appeared that after many months of fruitless thought

and experiment, during which the great inventor never went to bed (so I gathered), the problem went and solved itself, in the twinkling of an eye; by the accidental dropping of a screwdriver into the middle of an experiment!

Contemporary with this feverish method of research accompanied by propaganda, a quiet man here in England was working patiently at his invention of the carbon vacuum lamp. Never shall I forget my first sight of a Swan lamp. My home was a few miles from the town of Godalming, in Surrey, and Godalming in a strange burst of municipal enterprise, possibly induced by a dispute with the Gas Company, determined to light the streets of the town by electricity. Accordingly a dynamo was installed in Pullman's leather mills, not far from the town, on the River Wey where water power was available. The electric lighting of Godalming began on the 15th December, 1881, and very soon afterwards I went on a visit of inspection. I found the leather mills lit up by what I was told were Swan lamps. I remember speaking with a workman, a leather worker there, who had the glorious illumination of a Swan lamp all to himself. But he was far from enthusiastic about it and was inclined to prefer a tallow candle.

I found many more Swan lamps lighting the smaller streets of the town; but the High-street was illuminated by three arc-lamps, flooding the little sleepy town and the sky overhead with a blaze of glory.

When I saw them the street-lighting cables were laid in all innocence in the gutter, with nothing but their innocence to protect them from the wheels of carts or the hoofs of cart horses. I remember kneeling on the pavement and holding a pocket compass against one of those cables, just to see the needle deflect. Imagine my bewilderment when I discovered that, for some reason unknown to me, electricity for street lighting did not deflect a magnetic needle. That was my first encounter with an alternating current.

But of all the things I saw that evening, nothing impressed me quite so much as those Swan lamps, the first incandescent electric lamps I had seen. I shall not enter into the old controversy of who was the first inventor. So far as patents go, I suppose Swan and Edison shared the invention. But for us, the members of this Institution, our own countryman will always have the first place, and in the long list of our Past Presidents there is no more honoured name than that of Joseph Wilson Swan, the father of domestic electric lighting.

I must not leave those cables at Godalming lying in the gutter. Of course they ought to have been put underground out of harm's way. But in those days a street was regarded as the burial place for gas pipes and water mains, and anyone who proposed to lay an unhallowed electric cable in that consecrated ground came up against an immovable British institution, the Parish; and what goes with it, the Parochial Mind. Bury a *cable* in the street? It couldn't be done. It would need an Act of Parliament.

And sure enough, in less than twelve months from the time I have been speaking of, Chamberlain's notorious Electric Lighting Act was passed and the newly-born industry of public electric supply was snuffed out for the space of six years. Six years of arrested development. Now, a period of arrested development at the beginning of life, whether of a child or an industry, can never be made good. No Select Committees, no Royal Commissions, no Amending Acts of Parliament, can give us back those six years. From the year 1882 until the present time the business of public electric supply has been dominated by the Parochial Mind. One parish, one dynamo, has been the fundamental principle.

It is a relief to turn to another subject, the use of electricity as a means of instantaneous communication.

Telegraphy has had a long and curious history. It began with a wireless telegraph; an optical system. Yet, as we now know, the optical system was essentially an electric telegraph, working on a wave-length of about one forty-thousandth part of an inch, and using the human eye as the receiver. Then came the electric telegraph with wires to act as guides. And now we are using a wireless telegraph once more, but with a wave-length measured by hundreds of yards in place of a minute fraction of an inch.

An old optical telegraph between the Admiralty in London and the Dockyard at Portsmouth remained in use until somewhere about 1840, and both my father and my mother remembered quite well seeing it at work during their childhood. My own recollections of telegraphy begin in 1866, for I remember the laying of the Atlantic cable in that year: the first successful Atlantic cable. At breakfast time each morning my father used to read out of the newspaper to us children the daily message from the ship that was laying that cable. I was too young to realize all that it meant. I don't remember giving a thought to America. What impressed itself on the mind of a child was the fact that those men out there in the middle of the ocean were sending a message back to England through the Atlantic cable. There was a spaciousness about it, and a spirit of adventure, that appealed to the imagination. It was a good breakfast for a small boy.

Since that time the scattered countries all over the world have been linked together by a network of cables, to the incalculable benefit of mankind; a great work carried out by private enterprise, unrestricted by narrow-minded legislation. It is good to remember that it has been done almost entirely by our own countrymen. Theirs was a scientific knowledge; theirs the technical skill. And above all, theirs the magnificent courage. For it needed courage to lay enormously expensive cables on the bottom of the sea, with all its unknown dangers and obstructions. One obstruction they escaped: there are no Government Departments on the bottom of the sea.

So far all electrical communication had been by code; spelling out the message letter by letter. But presently we were to learn that speech itself could be transmitted and reproduced. It was in the year 1876, the year of the Centennial Exhibition at Philadelphia, that I first heard of Graham Bell's telephone. I had already heard of elaborate machines which were to speak. Somewhere I had read of one which was to contain hundreds of delicately tuned reeds, covering

the whole gamut of the human voice. And goodness knows what it was to contain in the way of other complications. Immense complexity: that was the dominant idea in my mind about machines for reproducing speech, when one morning in 1876 I read in the newspaper an account of some of the exhibits at the Centennial Exhibition. About half-way down the column, without a word of warning, I found myself reading a sentence that went something like this: "I have listened to Hamlet's soliloquy 'To be, or not to be,' spoken by Dr. Graham Bell's telephone." Barely a couple of lines, so far as I remember. I read that sentence again and again, trying to extract something more from it; one half of my mind full of wonder, the other half full of doubt.

But it turned out to be true and, little by little, I heard more about the telephone. A year later I saw a drawing of one, and a new wonder came to light. Where were all those imagined complications? To my astonishment there was an entire lack of complication. On the contrary the thing was incredibly simple. So simple that I at once set to work and made two Bell telephones, one to act as transmitter and the other as receiver; the two being identical, of course. My telephone consisted of a small bar magnet with some silk-covered wire wound in a coil round one pole, and a disc of thin sheet-iron which I cut out with a pair of scissors. I fixed these things inside a wooden baking-powder box which my mother gave me, and with my knife I cut a hole in the lid to let the sound into the transmitter and out of the receiver—always supposing that by some amazing miracle there should be any sound whatever to come out. I was already the proud proprietor of a telegraph line, and to this I connected my telephones, one at each end.

All being prepared I engaged the services of a lady as telephone operator. For simplicity I will refer to her as Jane. At that time Jane was about eleven years of age; nowadays we should consider that rather young for a girl telephone operator. Having stationed Jane at one end of the line with the baking-powder box at her ear, and strict injunctions as to procedure, I went to the other end and took up the other baking-powder box in order to speak to it. Then I tried to think of something to say. Next, I realized how silly it would be to speak to an inanimate object; actually to talk to a baking-powder box! However, I reflected that there was nobody there to see me making a fool of myself and so I made my first speech to the telephone. "Jane, can you hear what I say?" Then feeling even more foolish but a little excited, I put the baking-powder box to my ear. Instantly I became aware of the miraculous truth, for I heard a small but perfectly clear voice coming from inside the baking-powder box and saying: "Yes, I can hear you quite plainly."

I do not know how to describe what rushed into my mind when I heard that small voice. I hear the very sound of those words to-day as I did then and the wonder of it is as vividly present in my mind at this moment as it was 45 years ago.

Well, since that day a good deal of the glamour has been rubbed off the telephone. If anyone were to go outside this building and ask the first man he met what he thinks about it, he would probably tell you that the telephone is an infernal nuisance, mismanaged by the Postmaster-General. But the gibe is not altogether justified. It would be nearer the truth to say that our telephone service, with all its shortcomings, including the Postmaster-General, is a faithful reflection of our national temperament. At all events that is a consoling thought when we get a wrong number.

But I will not end on a controversial note. At the time I have been trying to recall, the elaborate system of telephonic communication which has come into use all over the world could only have been vaguely foreseen. The telephone at that time was just the latest wonder of a wonder-working age; a scientific marvel by which the spoken word could be instantaneously reproduced at a distance.

And what is it that performs this miracle of speech? Look at it again. This small magnet. This tiny coil of wire. This little disc of iron. These three things, and a container of some sort to hold them together—a baking-powder box will do. So arranged, this little disc of iron, a mere scrap of sheet-iron, has the power of speech. To-day it is speaking to the telephone user all over the world about his everyday affairs. And sometimes not without a touch of romance, as when it speaks to the lonely pilot of some aeroplane up above the clouds. Was ever so profound an influence on our daily life brought about by such simple means? I can think of nothing, no invention that approaches it. In supreme simplicity directed to a great end Graham Bell's invention stands absolutely alone.

MR. A. H. WALTON.

Mr. J. E. H. Gordon's System of Electric Supply, Great Western Railway, Paddington, 1884.

It is with pleasure and a little pride that one can look back nearly 40 years to having had the honour of assisting in carrying out some of the pioneer work of electric lighting in this country, especially as the work engaged upon at that time has proved the basis upon which all our present-day schemes of lighting and power are founded.

One remembers well the keen discussions which took place at meetings of the Institution between our old friends Colonel Crompton and Mr. Mordey, when each thought his system of lighting (direct current and alternating current respectively) was the more advantageous, and now to find that each is in certain cases dependent on the other.

Many of our younger members probably have never heard much about the single-phase alternating-current electric lighting installation put down by Mr. J. E. H. Gordon at Paddington, and it is of this historic work I shall endeavour to give a brief outline.

In those early days the only alternating-current ammeter we had was the Siemens dynamometer, a most excellent instrument but unfit for everyday use with engine-room staff.

The only voltmeter we had was the Cardew hot-wire

instrument, which was also far from robust, an essential requirement for practical use. As we all know, these instruments depended, in the case of the Siemens instrument, on a silk suspension, and in the case of the other on a turn of silk or thread round the indicator spindle, which operated on the expansion of the fine wire in the Cardew tube.

The question of calibration of these voltmeters with such mechanism was indeed difficult, and little or no reliance could be placed upon the instrument for any length of time; however, various methods of calibrating were tried, one being that by the Clark standard cell. This proved tedious and for some considerable time we had, in practice, to rely on our judgment as to when a standard lamp was incandescent, or, in other words, to rely on the lamp-maker.

In writing up my recollections after so long a period has elapsed it is somewhat difficult to go into detail. I shall, therefore, confine myself to the system and the carrying out of the work of the installation at Paddington.

The Gordon system of electric lighting was installed over the area between Paddington station and Westbourne Park of the Great Western Railway, and was undertaken by the Telegraph Construction and Maintenance Company to test the practicability of central station lighting, the district being $1\frac{1}{2}$ miles long and covering some 67 acres.

I should here state that Sir Daniel Gooch was at that time Chairman of the T.C. & M. Co., and also of the Great Western Railway. The contract was entered into in the early part of 1884, and on completion the contractors were to operate the plant continuously for 3 years except for 3 hours in the daytime on Sundays for testing purposes, the payment for this service being a fixed sum per annum. The Great Western Railway, however, took over the running of the plant after the first year of contract running. The T. C. & M. Co., as is well known, were makers of submarine cable, using as insulation gutta-percha, and this led to the use of this material on all our cables for this contract.

The design of the 8-ft. Gordon generators was commenced early in 1884 and, after much experimental work had been carried out at Enderby's Wharf Works, East Greenwich, the three machines and other apparatus required were built by the T. C. & M. Co.

The output of each machine was to be 400 kW at 150 volts when running at 180 r.p.m. with 28 poles, thus giving 42 complete periods per second. On completion of the plant the speed was decreased, owing to engine troubles, to 146 r.p.m., this giving a little over 34 complete periods per second.

Each machine was direct coupled to a vertical, twin, compound, tandem-type engine built by Messrs. J. & J. Rennie, developing 550 I.H.P. non-condensing when running at 180 r.p.m.

The field or rotating part, weighing some 22 tons, consisted of 56 drum type coils, 28 being mounted on each side of a wrought-iron disc or wheel built (conical shape) up of boiler plates. These field coils were carried on 6-inch cores which passed through the wheel, and at each end of each core outside the coils were fixed the pole-pieces. This field-magnet wheel was carried on a main shaft 8 inches diameter. One of the main bearings was designed as an adjustable thrust bearing of the loose disc type, this adjustment being necessary to keep the rotor equidistant from the stator coils on each side of the machine.

The stator consisted of wedge-shaped coils wound on a wedge-shaped hollow core of wrought iron, welded up. On each side of the machine were fixed 56 of these coils; these stator coils were connected up to make two complete circuits, that is to say, every other coil was connected to one of these two circuits. There were therefore 28 coils of each circuit on each side of the machine, and these were connected up two in series to give the voltage, and then in parallel to the main busbars provided for each machine.

The reason for separating the stator windings into two circuits was to avoid inductive effect of one coil upon its neighbouring coil; and for the purpose of distinction the two circuits were called "red" and "blue" respectively.

I have mentioned that the cores of these stator coils were hollow; this was to permit of water circulation, and to accomplish this the bolts for securing the cores to the machine frame were drilled through their entire length and thus the water from the jacket of the machine frame passed through the bolts to the hollow cores.

The method of keeping the voltage balanced between the two circuits with a common excitation was by short-circuiting pairs of stator coils by means of 2-way switches fixed near the main busbar of each machine.

The weight of each machine was approximately 45 tons.

There were three exciters installed; these were of the Crompton-Kapp type and were driven by a Willans 6-cylinder launch-type engine, the output of each machine being approximately 25 kW.

The speed of these exciters was varied according to the load on the alternator to which it was connected, by means of control shafting carried the whole length of the engine room, on bearings at the back of the main engines, and a quadrant and bevel gearing was arranged so that any exciter could be driven from the main engine position. An exciter switchboard was also provided so that any exciter could be connected to any alternator.

At this period little was done in the way of paralleling alternators, but we certainly tried it, although without success. The switchboard was arranged for the operation of two out of the three generators at any one time, or one machine could be coupled to the whole load.

I have already referred to the two circuits on each generator as red and blue respectively. The contract provided that we should supply a double system of mains in every room, building, or yard, half the lights being on one circuit and half on the other.

In the case of two generators operating at one time, each having red and blue circuits, these had again to be divided to meet the above conditions. The external feeders and distributing mains were therefore called "O" and "□" circuits, and, when two machines were running, one was connected to the "O" red and "O" blue feeders, and the other to the "□" red and "□" blue feeders, the distributing mains from

the feeding centres being connected in a similar way. It will therefore be seen that half the lamps in a room would be fed from the "O" circuit and half from the "□" circuit.

The necessary feeder switches were also provided to control the supply to the various feeding centres of the system. The exciting circuit to each alternator was also controlled from the main switchboard. The whole of the switches used on the board were of the flexible leaf type of heavy section.

From the switchboard, cables were run to connect up what was known as the "Gordon divided main apparatus."

The "Gordon divided main" multiple-type feeders were run out to the various feeding points which, at that time, were called "centres." The divided main consisted not of one wire but of a bundle of small, separately insulated cables connected to a busbar + and — at each distant centre. These divided mains were laid side by side in separate U-shaped troughs with cover, to each feeding centre.

There were 5 centres in all, 2 of which were located at different points in the passenger station, one in the goods station with a sub-centre fed from it by ordinary cables, and one each in the locomotive shed at Westbourne Park and the home, or dynamo, centre, this latter being fed from the engine-room.

Here I will explain the object of the divided main. It was primarily designed to obviate the use of expensive, heavy-section mains, if the pressure was to be kept within, say, 2 per cent of that at the generator end during the period of maximum load. The divided main accomplished this, and Mr. Gordon no doubt also had in mind that the contract provided for a given sum of money for only 3 years, and that it would be less costly to burn extra coal during the hours of maximum load for the 3 years' contract than to lay down expensive mains to be handed over at the expiration of that period. The voltage-drop decided upon in the case of the feeders to passenger and goods centres was 20 per cent (to 120) and to the loco' centre some 33 per cent (to 100). To obtain this drop at all loads the divided main, which consisted of a number of small, stranded, separately insulated cables in parallel, was varied in section according to the load, by cutting "in" or "out" the small cables of which the feeder was composed. It was hoped to accomplish this automatically by return control wires led from each centre to the generating station, and special apparatus was designed for this purpose.

This consisted of a cast-iron wheel on the front face of which was mounted hard wood as an insulator; and let into this were segments of copper on either side (right and left). By rotating the wheel slightly it was possible to put more or less of the segment of copper under the contacts on the fixed portion of the apparatus, each contact forming part of the feeder or divided main. The automatic part of the apparatus consisted of a solenoid and core, the winding being fed by the return wire from the centre, and the core was connected to a water-type Willans governor. Hunting was, however, set up, due to engine-governor troubles, which caused variations in periodicity, and the automatic feature was cut out.

There is no doubt that this method of keeping the voltage constant at a given point is a good one even with the present-day system of heavy feeders and distributing mains, and is well worthy of consideration by those responsible for laying a network of cables.

From the feeding centres distributing cables were run in duplicate, each of half the section required for the full load, it being part of the contract that half the lamps in any room, station or yard should be on one circuit and half on another when the maximum load was on and two generators were in operation.

In the offices and Great Western Hotel 4 115 incandescent lamps, each of 25 candle-power, were installed, and in the passenger and goods stations and various yards 98 arc lamps, each of 3 500 candle-power. In addition, two arc lamps of some 12 000 candle-power were erected at the front corners of the Hotel.

At the time this work was started, our difficulty was to find a suitable alternating-current arc lamp, and after much experimenting at the Greenwich works, alterations were made to the Crompton direct-current D.D. type of arc lamp. The alteration, as far as one can remember, consisted in reversing the positions of the shunt and series coils and in employing, instead of one core, two laminated solenoid cores insulated magnetically from one another. With this alteration the lamp operated satisfactorily.

The lamps were operated two in series, and in series with each pair of arc lamps was inserted an inductive resistance, which consisted of a drum of cast iron split on one side to prevent eddy currents, and then suitably insulated and wound with the requisite number of turns of double cotton-covered wire.

The carbons, 14 mm diameter, for use with these lamps which took 18 amperes, were also a matter of close investigation, their cost being a serious factor. Those manufactured by Messrs. Siemens of the soft-core type at that time gave best results, but the price, some 9d. to 10d. per foot, made the operation costly.

Messrs. Hardtmuth of Vienna produced a soft-core carbon about this time at about half the cost, which also gave good results, and it was with this make of carbon that the lighting commenced. Later, Messrs. Le Carbone of Paris supplied carbons almost of equal quality at about 2½d. per foot, which were adopted.

At the time when the contract was first put in hand, the loop and spring type of incandescent lamp terminal was the only one available, but the bayonet type was being seriously considered by the Ediswan Company. About the middle of 1884, Mr. Gordon drew up an elaborate series of tests to which the incandescent lamps were to be subjected before acceptance, such as photometer tests after having run a certain number of hours.

In due course the Ediswan Company accepted a contract for 10 000 25-c.p. carbon-filament lamps with bayonet-type terminals at 5s. each, and agreed to the tests set out by Mr. Gordon. On testing the lamps as deliveries were made, the rejections were found to be heavy, but the makers replaced the rejected lamps by others which passed the tests. Much to Mr. Gordon's surprise when offering them another contract on similar terms Mr. Gimmingham, of the Ediswan Company,

would not accept it, with the result that, due to the patent situation and monopoly they held, all the former rejected lamps, which we had carefully marked, were supplied as part of this second contract.

The plant was started up towards the end of 1885, when it was found that the generators required more power to drive them on open circuit than on load, due to inductive effect on the machine. The temperature of the stator coils also rose to a very high figure, in spite of the water circulation.

The plant was therefore shut down and the stator coils were taken out, unwound, and the cores slotted, it being Mr. Gordon's opinion that this would considerably reduce the working temperature. After rewinding the cores were replaced, the hollow bolts securing the cores to the frame were filled up, and water circulation around the frame of the machine only was relied upon. These alterations effected a slight improvement in the final temperature, but it was still so high that frequent rewinding of coils was necessary.

Mr. Gordon was urged to substitute laminated cores, but he was so satisfied that solid cores were correct that matters were allowed to remain. His strong opinion, together with the fact that in those days we had no means of testing the iron, may account for the failure to convince him that his views were not correct.

Whilst in the midst of all these troubles our neighbours in Gloucester-terrace applied through their superior landlords, the Ecclesiastical Commissioners, for an injunction to restrain the Railway Company from working the plant, alleging nuisance by vibration, noise, exhaust steam and smoke. We were aware that one of the engine crank-shafts was not machined quite true, and this had to be left somewhat slack in its bearings for operation.

In due course the hearing came on before Mr. Justice North and, after several days, when only the decision remained to be given, his lordship said he would deliver his judgment the next day. That evening I was much surprised to receive a visit from his lordship and Lady North at the works. He made careful inquiries about the defective engine shaft, and other details as to exhaust steam and smoke.

The next morning he also surprised all the Counsel employed in the case by telling them that he had been to see for himself. The result was, briefly, that we had to replace the defective shaft, condense the exhaust steam, and carry out the promise of the Railway Company to erect higher smoke stacks, the whole of which was carried out.

When current was first switched on to the feeders and only one machine was running, the lighting of both arcs and incandescent lamps appeared satisfactory. But when two machines were running (not in parallel) a severe pumping was set up in all the arc lamps. It was first surmised that this was the result of inductive effect in the " Gordon divided main " and for some time we were somewhat puzzled, but on going to examine the arc lamp inductive resistances, which also had a way of getting very hot (they were afterwards changed from iron to wood drums) and which were placed fairly close together, we found a continual change of note between the resistances fed from one generator, and those fed from the other generator. This change of note synchronized with the pumping in the arc lamps.

It was then apparent that the iron drum or cores of these resistances were acting inductively on one another. The resistances were then placed some 18 inches apart and the whole of the trouble disappeared.

A considerable amount of trouble was also experienced through breakdown of our Gordon divided mains (feeders) which were insulated with gutta-percha. These mains were laid underground in the 6-ft. way and it was some considerable time before we located the cause of the trouble. This was due to the small tank locomotives used for shunting purposes standing for some considerable time at one spot with their boiler feed injectors leaking hot water, with the result that this percolated through the ballast on to the feeders causing them to become a solid mass.

The location of these faults was also of interest. This was done by the loop method of testing, and on many occasions after testing the distance was marked off, and the ground opened quite close to the fault.

The 3 years' running of the contract commenced on April 21, 1886, and during the early months of this period we had anxious times and extremely long hours of hard work. However, after 12 months' running the Great Western Railway took over the plant. The carrying out of this work involved considerable sacrifice to all concerned to obtain success, for it was seldom that we worked for less than 12 to 15 hours per day during the experimental running period. Fortunately we had no interference from outside sources, our great object being to attain success.

Soon after the Great Western Railway took over the plant I set to work and got a few laminated cores built of the softest iron we could obtain at the Swindon works. These effected a very marked improvement in the temperature-rise and resultant efficiency of the plant, the output per pair of coils being increased some 15 per cent.

This old and historic plant has now been replaced, but I feel sure it will retain a place in the pioneering of electric lighting in this country.

I understand that tests were made of the old plant by Messrs. Kennedy and Donkin prior to its removal, but I have not had the pleasure of learning the results.

In carrying out the wiring for the 4 000 or so incandescent lamps at Paddington the usual method of jointing the individual lamp wires to the main was by cutting the insulation of costly distributing mains to pieces and soldering up the lamp wires and then re-insulating.

To obviate this damage and destruction to insulation of the mains the scheme of bringing all lamp wires to a central point was devised in 1888, and I propose to illustrate this on the screen. This system was first used, I believe, in the wiring of Whitehall-court and other large buildings.

I should also like to refer briefly to an interesting case of induction trouble which came under my notice in 1889. The Metropolitan Electric Supply were called upon to give a supply of alternating current at 120 periods to the Holborn Restaurant. In due course the con-

nection was put into the building and connected on to their positive and negative mains which were run separately in iron pipes. On switching on our alternating current a very heavy drop in pressure was observed on the lamps and severe heating was set up in their iron pipes containing one pole of the supply. To get over this, rubber-covered cables were substituted and the trouble ceased.

Some two years later, in 1891, the City of London Electric Lighting Company laid their single-core conductors in separate iron pipes, with the result that they also experienced a very serious drop in volts and, after investigation, discovered that we had already observed this effect of single conductors in iron pipes some two years before.

I well remember Sir William Preece, one of the consultants of the City Company, being somewhat upset at not having heard of our troubles earlier, and unfortunately for the City Company it cost a considerable sum to replace their single-core mains with the concentric type.

In conclusion, I would ask the Council's acceptance, on behalf of the Institution, of my collection of lantern slides and photographs illustrating the pioneer installation which I have described (four of these slides are reproduced in Plate XV).

MR. WALTER JUDD.

Submarine Telegraphy.

I will try to put before the Meeting some facts and observations connected with the 50 years during which I was intimately associated with submarine telegraphy —from March, 1869, to March, 1919.

At the first date, the only ocean cables existing were three across the Atlantic.

The number soon increased, as in that year cable communication was established with Egypt; in 1870 with India, Malaya and Java; in 1871 with Cochin China, Hong-Kong and Australia; in 1874 with South America; in 1876, New Zealand; in 1879, South Africa.

With all the above enterprises the name of Pender will always be identified.

Our President in his Inaugural Address quoted Lord Kelvin's farewell address in 1890, wherein Kelvin emphasized the debt owed to the late Sir John Pender, whose courage, enterprise and financial guarantees at the most critical period enabled the engineers and electricians of his day to carry out and materialize the great conception of linking up the whole world by submarine cables. His work has been continued by his son, Sir John Denison-Pender, who now presides over a world-wide system of cables, which probably exceeds the most sanguine anticipations of its founder.

Cables were laid by the Great Northern Telegraph Co. of Denmark in 1870 and 1871 between Siberia, Japan, China and Hong-Kong. On the West Coast of Africa, both coasts of South America and in the West Indies cables were also laid. Other countries have entered the field on a large scale; the original cables have been duplicated and quadruplicated, and further extensions made; the Pacific Ocean has been spanned from north to south and from east to west, with the result that from the mileage of a possible 10 000 in 1869 there are now 305 000 miles in operation, of which some 71 000 are Government-owned. This figure includes *all* submarine cables whether in shallow or deep water, the great bulk having been manufactured in this country.

The cables of to-day are of the same general type as was used in 1866; there have been some developments, chiefly, however, in the direction recommended by Heaviside, namely, to put the maximum quantity of copper in long cables. The ratio of copper to gutta-percha in the 1866 cable was 300 lb. copper to 400 lb. gutta-percha. This ratio has been more than doubled.

In shallow, tropical waters it was soon discovered that cables were quickly attacked by teredo and other boring worms which riddled the core, rendering the cables faulty and then unworkable. This serious difficulty was overcome by lapping the core with a thin brass tape, which defied the attack of the borers.

The question of including inductances in deep-sea cables, either by the Pupin or other methods, has been considered; but as regards the Pupin coils, it must be borne in mind that the cable exterior has to withstand great pressure, amounting roughly to 1 ton per sq. in. per 1 000 fathoms of depth. As regards the other methods, they were believed to be dependent on the discovery of an iron having several times the permeability of any such material known in 1919. It has been suggested that if a lasting insulator could be found having a dielectric resistance amounting to only a small fraction of that given by gutta-percha, a cable could be produced having small retardation and distortion, and an attenuation which would not be too great.

Although I am not aware that either of these suggestions has yet materialized, it would be unwise to say that either was impossible, or that perfection has been arrived at in the design, construction and working of submarine cables.

The machinery for laying and repairing cables took a practical form at an early date, and except for detail improvements remains much the same now. Volume 5 of our *Journal* contains a reprint of an admirable paper dealing with this subject, read before the Institution of Civil Engineers in 1858, by Mr. J. A. Longridge and Mr. C. H. Brooks.

In the earliest days of 1865 Lord Kelvin solved the problem of the method of operating the cables when laid. His mirror galvanometer was for some years in universal use, until the development of the siphon recorder displaced it. Both instruments, except for small modifications making for easier adjustment and maintenance, remain practically unaltered to the present day.

In the early days of simplex working the outfit required was of the simplest; a signalling key, a few cells of battery, a "send and receive" switch, a Varley condenser of tin-foil and thin sheets of gutta-percha, calibrated in units of "1 mile of Atlantic cable," a

lamp and scale: these formed the unit for working an Atlantic cable.

It will be seen then that, after the initial failure of 1858, the next attempts in 1865 and 1866 showed the type of cable. The methods of laying and repairing and the apparatus for operating when laid had already been developed by the truly great engineers who were the pioneers in this enterprise.

The methods of localizing faults and breaks then available were the Lumsden, the Blavier, the fall-of-potential, and the loop tests. Later were produced the Kennelly break test, the Anderson and Kennelly overlap test to faults, the Gott capacity test, and a number of variants of these, which together give to a competent observer an extraordinary accuracy of localization.

Modern apparatus for operating cables has lost its pristine simplicity. The first great change was the introduction of duplex, in connection with which I must mention the names of Desauty, Harwood, and Smith of the Eastern Telegraph Company, Stearns of the Atlantic cables, and Muirhead of the consulting engineers. After supplying an artificial line which represents the closest possible reproduction of the electrical constants of the cable, the art of obtaining a perfect balance on a long cable still appears to depend upon the personal skill, intuition and experience of the officer in charge of this duty; it remains a process of trial and error.

A demand early arose for a relay for long cables. The Brown and Allen jockey relay functioned satisfactorily on short cables, and the Gulstad relay was, and is, a most efficient instrument, but still not sensitive enough for long lines. As it was, some years elapsed before both S. G. Brown and Muirhead produced methods which at last established automatic re-transmission between long cables, much to the advantage of the service—both to the undertakers and the public.

Many people had tried to produce a relay with "butt" contacts and had failed by reason of the "stiction" between two like metals. To W. Gaye is due the observation that such contacts should be between two different metals such as gold/silver, platinum/silver, or platinum/gold. This led to a resuscitation of the jockey principle—which provides an automatic adjustment of the wandering zero due to earth or cable currents, and an apparatus was evolved which proved an efficient relay.

The next advance was the evolution of a magnifier or amplifier, the best known type of which is due to Mr. E. S. Heurtley. It is possible, however, that the thermionic valve may play a part here.

There is now a tendency to revert to the Morse code instead of the Cable code hitherto universal on long cables. This has been made possible by adapting the Gulstad principle to more sensitive apparatus.

I have purposely avoided any detail in this sketch, as neither the time nor the occasion would permit of my so doing; and, having now given this brief outline, I will endeavour to recall some other aspects of this enterprise.

Only those who were present at the first landing of a cable to connect outlying communities to their home countries can have any idea of the excitement and pleasure produced.

Nowadays there are no worlds remaining to conquer in this sense.

Such a new connection in those days necessarily involved a considerable change in commercial routine. When, as in the East, the arrival of the cables almost synchronized with the opening of the Suez Canal, this routine was so changed that those firms which did not change with the times sooner or later disappeared. The double acceleration of advices and transport also allowed of the advent of small firms with small capital, and the proud position of the merchant princes of the old times was attacked from all directions.

The appearance in these regions of a definitely electrical element stimulated the other branches of electrical development; thus, for example, I was able to assist in the introduction of the telephone in one colony, and the establishment of electric lighting in another.

The arrival of cables resulted in the establishment of land telegraphs in Japan (under British engineering auspices) and in China (under Danish engineering auspices), and there is no doubt that these Western methods smoothed the way for the introduction of railways.

The social effect of these new communications established by the early cables was marked. The feeling then existing, of distance and isolation, was lessened. The daily instalments of world news, thoughts, and movements had a distinct psychical as well as physical effect; it may therefore be permissible to invert the copybook maxim and say: "Good communications are good for manners and men," and in this spirit the cable world has welcomed "wireless" and received it with interest and admiration, believing that there is room for both systems, and that the resources of both will be fully taxed to meet the requirements of the future.

Submarine cables have played a useful part in war. Thus, in 1882, during the bombardment of Alexandria the cables were taken on board a repairing ship and communication then established with London.

In 1885 during the Pendjek controversy with Russia, a cable was laid from the mouth of the Yangtzse River to Port Hamilton, a naval base formed in a group of islands off the coast of Corea. The British fleet there was thus put into communication with the rest of the world.

During the South African war the existing communications were maintained, and an additional cable was laid to secure the communications with London.

During the late war all the neutral and allied Fronts were served by submarine cables, and it was a matter of pride to those concerned that, in spite of all the difficulties of maintenance imposed by the state of war, the necessary communications never totally failed. However much the commercial and social traffic might be delayed, the urgent war communications were assured. Various strategic cables were laid, concerning which details are unnecessary. Repairs to cables which normally employ a fleet of vessels were naturally obstructed; but at great risk and with an immunity from casualty which is an outstanding tribute to the

efficiency of the Admiralty Intelligence Department, the necessary repairs were carried out.

The risks were great, for a cable steamer grappling, or picking up cable is an ideal target; these risks, however, were faced by the officers and ships' companies with perfect coolness and their task carried out as efficiently as in peace time, and their good work was recognized by the authorities.

The little vessel charged with maintaining the cables around Gallipoli, whose operations were almost incessant, worked frequently under fire but escaped without casualty.

The shore staffs in the whole cable world grasped the fact that they were engaged in the maintenance of vitally important lines of communication. Some were in danger from hostile raiders as at Fanning and Cocos, at which latter place they turned to their younger sister, wireless, and so brought about the destruction of the "Emden." The staff, generally, sacrificed themselves at all times to the requirements of the time; but though they recognized that the duties they carried out were all-important, I think they never quite got rid of the feeling that, compared with the trenches, theirs was on the whole a "cushy job" All the more honour to them that they did their job so well and cheerfully.

In concluding this sketch I wish to express my belief that submarine telegraphy will continue to bear its great part in social, political and commercial advancement, and in this connection it is interesting to note that not only was there no increase in cable tariffs during the war, but that, actually, cheapened and gratis facilities were given for communications between the troops and their overseas homes.

The Chairman: I have to inform you that, during the past week or two, the Institution has been in touch with Mr. Oliver Heaviside, with a view to doing him some honour. We are not yet in a position to say what he would like or what he would accept, but I shall raise the point again later. The question will be considered of sending him a greeting from the whole gathering present at one of these Commemoration Meetings.

The meeting adjourned at 6 p.m.

WEDNESDAY, 22 FEBRUARY, 1922, AT 8.30 P.M.

(Held in the Institution Lecture Theatre.)

Mr. C. C. Paterson, O.B.E., Vice-President, in the chair.

The Chairman: We have again to deplore the unavoidable absence of Mr. Highfield from the presidential chair this evening. That his indisposition is not serious is really our only consolation. He has thrown all his energy and thought into the arrangements for these Meetings, and his own disappointment at having to be away is, I know, as keen as ours. I am not going to introduce Professor Fleming this evening. He taught many of us in our student days, and he still continues to teach all of us. But we have come here this evening to do that which we are all apt to do too seldom—to receive inspiration to face the future, by dwelling for a time on the past. There is no one better fitted to help us or to guide us backwards through those very early days than Professor Fleming, and I have great pleasure in calling on him to give his lecture.

Professor J. A. Fleming then repeated his lecture on "Michael Faraday, and the Foundations of Electrical Engineering" (see page 379).

Sir Oliver Lodge: It was a happy idea of the Council to have, as part of the Institution's Jubilee celebrations, a pious manifestation and reminiscence of the work of one who is really the father of all electrical engineering—Michael Faraday. I never had the pleasure of seeing or hearing him, because I was not awake to science sufficiently early. I do not know whether Professor Fleming ever heard him; he and I were students together in chemistry at South Kensington, but it was just after Faraday's death. The choice of the lecturer could not have fallen upon a better man. The trouble he must have taken in producing and reproducing these classic experiments, which are in every textbook throughout the world, and in showing them to us as nearly as possible in the way in which they were done in Faraday's time, deserves our most cordial thanks. I have, therefore, great pleasure in moving a vote of thanks to Professor Fleming. With regard to the experiments which have been shown, I rather admire his pluck in giving the experiment on self-inductive capacity. Electrostatic experiments are not very easy to perform, and I confess I should have hesitated a little about trying to show that particular experiment to this audience. Think of the skilful manner in which he has covered the ground in one short hour, knowing that he had an expert audience before him who were familiar with the cold facts, but who liked to hear them once more brought forward in a biographical atmosphere. Many reminiscences occurred to me as he spoke. For instance, I know how enthusiastic Faraday was when he drew that spark from the magnet. I do not know whether he could have had any intuition of all the things that some of those in this room have been instrumental in producing from that experiment, but he evidently felt that there were the seeds of great things in it. Yet tales are told of its curious reception. One auditor—an important man—said to Faraday, after he had demonstrated it: "What is the use of that?" That is the time when Faraday is said to have replied: "What is the use of a baby?" Another auditor, a dignitary of the church—I am told a bishop—lamented its production. There had been at that time a great number of hayrick fires; arson was

prevalent. The bishop said: "I deeply lament putting increased facilities into the hands of the criminal." I do not know that the phenomenon could be used to set fire to hayricks, but we do know that science can put facilities into the hands of criminals. However, no science can stop on account of consequences; we are bound to go on. Faraday's experiment to demonstrate the connection between magnetism and light was, as the lecturer said, a marvellous anticipation, and at the time it was made the world was not ripe for this discovery. Faraday tried to establish that connection in every possible way, and, as Professor Fleming has said, the apparatus which he used was very complicated, so that it is marvellous that he succeeded. No one understood it at that time. Kelvin understood it later, as also did Maxwell. Tyndall, who compared the peaks of Faraday's work with those of the Swiss Alps, eloquently describes it. He says: "This magnetization of light I will liken to the Weisshorn among mountains—high, beautiful and alone." It remained alone until the autumn of 1896, when Zeeman extended it. It was the conception of magneto-optics. The lecturer concluded with some words about Faraday as a man. Faraday's name is very little known to the general public, compared with that of much smaller men. Somehow or other, his simple secluded life has not excited public admiration. It is well that electrical engineers should recognize their debt, and should, on this and other occasions, show their appreciation and admiration for the wonderfully beautiful simple life of Faraday.

Sir Richard Glazebrook: I am glad to have the opportunity of saying a few words with regard to the lecturer himself and the work he has undertaken in bringing this lecture before us I take it that if we analyse the facts that we have learned to-night and think about them, there are few in this large audience who will consider that they have been told anything very new The facts of electromagnetism, the discoveries of Faraday, are now known to every student and electrical engineer. Yet, at the same time, I am sure we feel that we have gained a new interest in all these facts; the important laws which we learned from Faraday and the wonderful discoveries which he made become to all of us very different things after hearing the Lecture that Professor Fleming has given us, and after seeing, on this table, apparatus which is historic in the truest and strictest sense—apparatus by which the whole history of the world has been altered and changed. It is hardly possible to conceive what the world would be like now without these simple experiments that Faraday performed 70 or 80 years ago. As Sir Oliver Lodge has said, we owe a deep debt not only to Professor Fleming for the way in which he has brought this matter before us, but also to the President and Council of the Institution for the idea of celebrating this Jubilee by calling our attention to facts of fundamental importance in the history of the progress of our science, facts which we owe to that great man Faraday, whose work and whose life have been so clearly and eloquently put before us to-night. I have pleasure in seconding the vote of thanks.

The vote of thanks was then put to the meeting and carried by acclamation.

Professor J. A. Fleming (*in reply*): It has been a great pleasure to me to have had the privilege of delivering this lecture during these Commemoration Meetings, but I cannot say that I am very satisfied with my fulfilment of my duty. The subject is a very difficult one to handle. To present Faraday as a man and an investigator appropriately is a task entirely beyond my powers. It is, however, unnecessary; we have his writings, and, more than that, we have his achievements and above all himself.

The meeting then adjourned.

THURSDAY, 23 FEBRUARY, 1922, AT 3.30 P.M.

(Held in the Institution Lecture Theatre.)

Mr. C. C. Paterson, O.B.E., Vice-President, in the chair.

The Chairman: Those of us who were here yesterday afternoon and evening, and especially, perhaps, those of us who are of the later generation of electrical engineers, found it a good thing to listen to our seniors and to hear from them something of the battles which they fought and to learn of the trials through which they went to make good the heritage into which we in our turn are entering, but which many of us feel we have so little deserved. We liked their humour as well as their courage, and we admired also their reverence for the memory of their predecessors, in whose steps they followed. Our President, Mr. Highfield, has done a great service to the Institution in giving its members, through the present Meetings which he has initiated, an opportunity of hearing some of the distinguished men of our own time, distinguished not only because of their achievements but because of the high traditions they have maintained throughout lives of strenuous work. I have first of all to call on Dr. Eccles to propose a resolution which I shall ask Mr. Atkinson to second.

Dr. W. H. Eccles: Those of us who were here yesterday afternoon will remember that Sir Oliver Lodge suggested that on the occasion of these Commemoration Meetings we might with graciousness send Mr. Oliver Heaviside a message conveying to him the appreciation of the electrical engineering profession for the theoretical work which he has done. The Council have since had the opportunity of discussing the matter with Sir Oliver Lodge, and have agreed that his suggestion would be a very good one to take up, and we have drafted a form of words in

the nature of a message to Mr. Heaviside, which I shall later ask members to approve. Mr. Oliver Heaviside's work consisted, for a large part, in introducing Maxwell's theory to those who were not skilled in the mathematical methods used by Maxwell. In particular, he introduced a vector algebra which to him seemed simpler than the ordinary classical mathematical methods. Unfortunately, the orthodox mathematician at that time found that method very much more difficult than the method he had already learned, and poured cold water upon it. That was no doubt responsible for the fact that Heaviside's work was not studied in the schools as it might and should have been. Other countries, I think, were less slow to see the value of his work and, in fact, Lorentz, who is responsible for much of the theory of the electron and the relations of the electron to matter, very early adopted Heaviside's methods, and nowadays even the pure mathematicians who are writing books on the Einstein theory largely utilize his methods. His methods have, as a matter of fact, nowadays been introduced into pure mathematics, although 30 or 40 years ago the pure mathematicians would not accept them. In that direction he was ahead of his time, and on the physical as well as the mathematical side we have to admit that he was much ahead of his time. In particular it is well known that the submarine cable, which was studied by him, was very badly understood at the date he published his early papers, and it is owing to his suggestion as to the value of self-inductance that we have the loaded submarine cable of to-day, and can carry speech without distortion, or with a permissible amount of distortion, some 3 or 4 times further than could be done without these distributed loading coils. It is true that Pupin in America gave precise details as to how to place these coils and how to make them, and he protected, in the Patent Offices of various countries, his particular application of the principle originated by Heaviside, but he—and everyone else who has studied the subject—admitted that Heaviside had all the information, except the last arithmetical details, in his hands, and he gave it to the world at large without attempting to protect it, as he might have done, or to make money out of it. In another part of his work he showed similar insight. In the very early days of wireless telegraphy, when Marconi was trying to telegraph across the Atlantic by means of Hertzian waves, there was much scoffing in most of the scientific and electrical journals about the impossibility of electric waves travelling from England to Canada over the mountain of water, something like 150 miles high, that a straight line drawn between them would have to traverse, but Heaviside pointed out that the upper atmosphere was very probably permanently ionized, and was very possibly as good a conductor as sea-water itself. Really, therefore, these electric waves have to pass between two conducting spherical surfaces. At that date (about 1901) I was so impressed by the idea that I nicknamed the upper layer the "Heaviside layer," and that name has remained, and we who are interested in wireless telegraphy regard the Heaviside layer as being just as important for our purposes as the surface of the earth. Heaviside is in that way commemorated for years—perhaps centuries—to come. The resolution is that we should send him the following message:

"The members of the Institution of Electrical Engineers assembled at the Commemoration Meetings now being held to celebrate the 50th anniversary of the first Meeting of the Society of Telegraph Engineers (now the Institution of Electrical Engineers) with their thoughts directed to all those who in earlier days laid the foundation of the science and industry which the Institution represents, desire to send a message of greeting and remembrance to Mr. Oliver Heaviside, F.R.S., Honorary Member of the Institution.

"In the course of the Meetings they have been again reminded of and have recognized the great importance of the classic work achieved by Mr. O. Heaviside and published by him in his papers and writings from 1887 onwards, and especially of his discovery of the importance of inductance in circuits for the transmission of telegraphic and telephonic signals without distortion, and of him as the originator of the methods now being universally applied for this purpose; and in no less measure of his investigations and discoveries relative to the propagation of electromagnetic waves in space, the results of which are now being utilized in wireless or space telegraphy and telephony.

"They are convinced that, as now, so in the future, the name of Heaviside will rank among those of the great founders of the science of Applied Electricity."

Mr. Ll. B. Atkinson: Dr. Eccles has given a brief résumé of Heaviside's work, and I remember very well the early papers that were published by him and how many of us struggled to understand them, but with very little effect. I think it was Maxwell who said that every advance in pure mathematics has arisen from the endeavour to solve a physical problem, and the difficulty which Heaviside found in regard to some of the problems he was attacking, was that he did not see how he could use the classical methods of mathematics to solve them. He gave much time, therefore, to introducing a new system of vector algebra, thereby excluding from a clear understanding those who were too old to study mathematics. But he gave all the facts in words and there is much to be learned from them, even for those who are not conversant with his mathematics. As Sir Oliver Lodge said yesterday, Heaviside's work has not been recognized as fully as it should have been, and I therefore second the resolution with great pleasure.

The resolution was put to the meeting and was carried unanimously.

The following addresses were then delivered and the meeting adjourned at 6 p.m.

SIR CHARLES PARSONS, K.C.B., F.R.S.

My early acquaintance with dynamos commenced while serving apprenticeship at the Elswick Works, Newcastle-on-Tyne, in 1877, where I was permitted to make an epicycloidal engine of 10 horse-power with four opposed cylinders revolving with the crankshaft, but at half the speed, and for a time it drove a Siemens dynamo at 700 r.p.m., giving current for a powerful arc lamp on the Elswick Jetty. Among other things, I experimented with carbons drilled down the centre and filled with chalk, which arrangement much increased the light. The manufacture of this engine was subsequently undertaken by Messrs. Kitson, of Leeds, and about 40 were made from 10 to 20 horse-power for driving dynamos. Continuous lubrication by a pump, and a frictional spring coupling, were features in this engine, but though more economical than the Brotherhood engine which held the field at that time for the direct driving of dynamos, it was eclipsed by the Willans engine which superseded it.

About the year 1884, circumstances being favourable, I determined to attack the problem of the steam turbine and of a very high-speed dynamo and alternator to be directly driven by it. The work commenced with very small-scale experiments, and in such a way that should a few failures occur and re-design become necessary, the expense would not be too serious.

I will restrict my remarks chiefly to the high-speed electrical side, which involved quite as much work as the turbine.

The electrical data available in 1884 upon which to work were very scanty. Little was known quantatively about hysteresis or about eddy-current losses, and consequently considerable margins were necessary when designing for periodicities of magnetization 30 to 50 times greater than those then in practical use. A speed of 18 000 revolutions per minute was chosen as being suitable for obtaining theoretically a moderate degree of economy from the turbine, and the estimated output was 10 b.h.p. The data for the design of the dynamo were obtained by analogy from the published performances of an Edison, a Siemens and a Burgin dynamo, with respective surface speeds of armature of 43·21 and 42½ ft. per sec. Selecting an external diameter for the armature of 2⅝ in., the equivalent surface speed was about 200 ft. per sec.

To guard against the unknown but greatly increased heating at 300 periodicity as against 6 and 10 in the Edison and Siemens dynamos on which the design was based, a density of field of one-half that of the Edison was aimed at, and the E.M.F. calculated accordingly as directly proportional to the surface speed and the total length of active wire between brushes. The voltage was 100, the length of core 8 in., and 96 conductors 0·08 in. over the insulation, of round copper, were laid on a smooth core composed of thin sheet-iron 0·015 in. thick insulated with paper threaded on to a hollow steel shaft through which lubricating oil passed for cooling purposes. The end windings were spiralled in two layers, and the whole bound by phosphor-bronze wire of 60 tons tensile strength. The commutator had 12 sections, 4 convolutions per section. The density in the armature conductors at full load was about 9 000 amperes per sq. in., but thanks to the small radial depth of copper the resulting temperature was not excessive. The efficiency of this dynamo was about 80 per cent, and the steam consumption of the plant about 150 lb. per kWh.

This little turbo worked satisfactorily from the start, minor alterations being found necessary, only perhaps excepting the commutator, which, after several designs had been tried, was finally made of bars in short sections held by dove-tailed steel rings with asbestos insulation, which stood up well against the great centrifugal force. The cooling by oil circulation through the shaft was found to be inefficient, and dirt in the oil accumulated rapidly under centrifugal force so that it was not repeated in subsequent dynamos, air cooling being found sufficient, and fluid cooling was not again attempted till a much later date.

This plant worked regularly for some years supplying current for lighting experimental shops, including the early commencement of the Sunbeam incandescent lamp works at Gateshead-on-Tyne, where incidentally I may mention we constructed what I believe was the first quadruple stage exhaustion air-pump with 12-in. low-pressure cylinders, 2-ft. stroke, and automatically worked valves, which gave a vacuum about equal to the Sprengel pump.

The electrical constants of this the first dynamo have been re-examined and found to agree closely with modern dynamo practice modified to suit the speed of 18 000 r.p.m.

The same design was followed with minor improvements during the four following years in about 360 turbos of from 1 kW up to 75 kW output (see Plate XVI), which were chiefly used on board ships of the mercantile marine, Atlantic liners and warships.

The first turbo was placed on a ship in 1885, and a similar one was shown working at 12 000 r.p.m. at the Inventions Exhibition of that year in London.

It should be here remarked that from 1885 onwards improvements were being made to increase the efficiency of the turbine. The ratio of expansion was increased, the curvature and formation of the blades and other details improved, and the velocity ratio of blade to velocity of steam increased, so that in 1888 the consumption of a 32-kW turbo with 90 lb. steam pressure and non-condensing had fallen to 34½ lb. per kWh.

In 1887 some ten turbines of 15 kW to 32 kW supplied current for the lighting of the greater part of the Newcastle Exhibition with high-efficiency "Sunbeam" incandescent lamps.

The filaments were of "tar putty" with 4 per cent of zirconia, the effect of the zirconia being to reduce the resistance as the lamp grew older and the glass

darkened, thus maintaining the efficiency. The lamps were of from 100 to 1 000 candle-power and consumed from $1\frac{1}{2}$ to 2 watts per candle; the short life of 200 to 500 hours was accepted as being the most efficient under the circumstances. This was, I believe, the largest incandescent lamp exhibition of the kind up to that period, and certainly the most efficient.

Dr. William Garnett, the Principal of the Durham College of Science in Newcastle-on-Tyne (now the Armstrong College), was the technical adviser to the lighting of the exhibition and evinced the greatest interest in all new developments—and had previously on several occasions tested turbines.

The first high-speed alternator driven by a non-condensing turbine was made in 1888; it had a revolving single-phase armature for 75 kW at 4 800 r.p.m., four of these machines were supplied to the Newcastle & District Electric Lighting Co. for the initial lighting of one-half of the town under a Provisional Order. The armature body was a smooth laminated cylinder, and the conductor was wound in a single layer around thin longitudinal wood slabs keyed into the core so as to cover the whole remaining surface, and after an insulating covering had been applied, it was bound tightly with piano-wire.

From the commencement it was recognized that very high economy in fuel might be reached with the turbine; that the efficiency would be doubled by condensation; and that the efficiency would increase rapidly with the size, and more so than in the case of the reciprocating engine. In 1888 some estimates were made, guided by experience to that date, which indicated results not far short of those obtained to-day. Partnership difficulties, however, at this period seriously interfered with experiments and manufacture for several years.

Faraday had made a unipolar motor for lecture demonstration of which we were reminded by Prof. J. A. Fleming at this Commemoration, and it may be of interest to mention here, that in 1887 a unipolar dynamo was made to be driven by the original turbine at 18 000 r.p.m. The iron shaft was 3 in. in diameter and passed through the positive and negative poles of a separately excited magnet. Copper tubes were shrunk on the parts of the shaft between the poles and outside the poles, upon which the brass-wire brushes rested. At full speed and excitation it gave 1 volt when delivering 1 000 amperes, 500 amperes on each side—and 2 volts on open circuit; it could weld two $\frac{1}{2}$-in. round iron bars together. Another unipolar dynamo was built in 1902 according to Prof. G. Forbes's homopolar design, for Mr. E. Askeroff. At 4 500 r.p.m. it gave an output of 10 000 amperes at 5 volts and of 5 000 amperes at 7 volts. The shaft was 8 in. in diameter. The brushes were of thick sheet copper cooled by continuous streams of soapy water. Dynamos of this type have a very restricted field.

The first alternator to be driven by a condensing turbine was of the same type as I have described but for 120 kW, and was built for the Cambridge Electric Supply Co. in 1891 (see Plate XVI). It was tested the following year by Prof. J. A. Ewing on behalf of the municipality of Cambridge, and subsequently by Prof. G. Forbes and Sir Alexander Kennedy.

Some doubt having been expressed as to the accuracy of instruments for measuring alternating currents and voltages, a direct-current armature for 250 volts was specially built for the tests, but the readings of kilowatts with the two armatures proved to be in close agreement with each other.

In this connection it may be of interest to recall that the Corporation of Cambridge had obtained, several years previously, a Provisional Order, but taken no further steps. However, in 1891 they decided to transfer their Order on the understanding that a company should be immediately formed to carry out the work and assume the responsibilities under the Order. Further, as it was understood that turbo-alternators were to be used for the generation of the current, many eminent men in Cambridge having, however, expressed grave doubts as to their suitability for the purpose, the then Professor of Engineering was requested to report on the subject before the Corporation could finally agree to the transfer. His report pronounced turbo-alternators to be suitable, a consumption of 27 lb. of steam per kWh being recorded with 100 lb. steam pressure at 465° F. and $28\frac{1}{2}$ in. vacuum.

A simple method of ascertaining the losses that exist in an armature was used a good deal on the early plants. The machine is run up to full speed and voltage on the throttle and, when steady working conditions are established, loads of small amperage are thrown on and off and the steam pressures recorded. From the data thus obtained the relation between pressure and load in watts can be determined. By separately exciting the machine the power absorbed with and also without excitation is determined. The conductors may then be removed and replaced by wood, and the binding wire replaced to its original smoothness and same windage loss. The eddy-current loss of the conductors can thus be calculated.

In this way a 24-kW armature was tested at 8 400 r.p.m. and the figures were:

Current to excite field	360	watts
Total eddy current and hysteresis loss in armature	1 441	,,
Brush friction on commutator ..	1 010	,,
Calculated I^2R loss in armature, 0·003 ohm hot	270	,,
Total electrical losses	3 081	watts

The total loss in armature was made up of:

Steel piano binding wire ..	394·6	watts
Armature core and shaft ..	723	,,
Copper conducting wire, by difference	320·4	,,

The loss in brass or phosphor-bronze, or delta metal binding wire was inappreciable, but all were found unreliable and caused several breakdowns; probably season cracking was the cause.

In 1899 two 1 000-kW turbo-alternators, 4 000 volts 1 500 r.p.m., were ordered for Elberfeld, Sir William Lindly being the Consulting Engineer. They were tested before despatch and the consumption at full load was $18\frac{1}{4}$ lb. per kWh with steam at 125 lb. and 14 deg. C. of superheat. These were the first turbines to be imported into or used in Germany, excepting those of the de Laval type.

Up till 1912, direct-current armatures were made of the drum type similar to those I have described and in sizes up to 1 200 kW, but for a period of three years from 1889 to 1903 we were debarred from this type by the partnership difficulties to which I have referred. During this period the Gramme type had to be used, which was fairly satisfactory up to 200 kW. For sizes beyond this, heating of the shaft to a serious extent was caused by the cross field within the ring, and asbestos insulation was necessary. The largest made of this type was 400 kW, with two armature rings and two commutators.

Reduction gearing having been proved to be efficient, reliable, and commercially satisfactory for the transmission of large powers in 1911, direct coupling of high-speed direct-current dynamos was totally abandoned in favour of geared low-speed dynamos.

The first geared d.c. dynamo was sold in 1913.

Alternators, however, have been, and still are, direct-coupled to the turbine in most cases.

The revolving type of alternator armature continued much on the lines which I have described, but as sizes and voltages increased it became more difficult to secure satisfactory insulation, and, because of the great centrifugal force, it became difficult to provide sufficient copper to reduce the heat gradient through the thicker insulation. For these reasons principally, since 1903 the revolving field type has been universally adopted.

The first alternator with a rotating field was of the salient-pole rotor type for 2 000 kW, 6 000 volts three-phase, 1 200 r.p.m., 40 periods, and was installed at Neptune Bank, Newcastle-on-Tyne in 1903, but in later years fields of the barrel type have been adopted, with the exciting coils buried in slots and retained in position by dove-tail keys and the end windings by caps of bronze or of non-magnetic steel alloy. This formation was found to lend itself more readily to the requirements of the rapidly increasing sizes of alternators, which by 1911 had reached 25 000 kW, 0·95 power factor, at 750 r.p.m. in the turbo-alternator supplied to the Fisk-street station of the Commonwealth Edison Co., of Chicago, in 1913. Alternators of 12 500 kW are now operating satisfactorily at 3 000 r.p.m., and at the present time alternators are being built of 20 000 kW capacity, 0·8 power factor at 1 500 r.p.m. and also 15 000 kW, 0·8 power factor at 3 000 r.p.m. In the construction of these machines the finely-stranded type of armature conductor is used, with each strand insulated and spiralled several times in a conductor length, a formation to which we have adhered from the commencement and found satisfactory. Eddy currents in such a formation of conductor are reduced to a negligible quantity.

With the increasing outputs at high speeds, the cooling by ventilation has become a very important matter. It is found that the more efficient separately-driven fan is in every respect preferable to a fan mounted directly on the rotor and a scheme of ventilation is used which assures a uniform cooling of both rotor and armature throughout their length; this effectually eliminates hot spots. The closed system of alternator ventilation is now also being adopted, with its attendant advantages.

We have carried out experiments with the water-cooling of alternators, both armatures and rotors, but with only satisfactory results in the case of the latter. There are at present about 100 000 kW of machines running satisfactorily with the water-cooled rotors; owing, however, to the increased complication involved, its advantage over the usual schemes of air ventilation is questionable.

DR. S. Z. DE FERRANTI.

I have found the very greatest difficulty in putting together anything to say this afternoon. It is a hard task to deal with a period of 50 years and to attempt to say anything with regard to it that will make a connected story. It may be thought, perhaps, that I might relate some of the experiences I had with the starting of high-tension electric supply in London—the Grosvenor Gallery installation. It might be thought even that I might go a step further and give some account of what was attempted and what was done at Deptford. But I find, on making these attempts, that to give any connected account which would be interesting of either of these two undertakings would not be a matter of 20 minutes but more probably a matter of several lectures; and that, in order to deal with the subject in an interesting and accurate manner, it would be necessary to give a very considerable amount of time and thought to it, and to collect a great deal of material from the various people who took part in the work.

I shall not, therefore, attempt to do either of these two things. I shall not try to give any sort of a record of electrical progress; I simply propose to take the course of telling those present how I got into electrical work, and how things struck me from time to time as I went on. There is another difficulty, in the subject in this form, because it is always hard to speak of oneself or one's own work. But, if it is possible to overlook this, and I may be forgiven for putting forward these things in this way, I shall endeavour at least to show how things appeared to me from time to time.

When this Institution was holding its first meeting, which occasion we are now commemorating, I had not reached the age of eight years. I think I can truly say that I had then no interest in electrical matters, although I had been concerned in a very forcible demonstration of electrical power in so far as I had slept in a house which had been struck by lightning, of which the upper front wall had been knocked out and a gas pipe fused. However, I slept peacefully through it. What effect it may have had on my after-work I should not like

to try to estimate. If my contact with the demonstration had been closer, it might have been my last electrical experience.

Now, at the time, although knowing nothing of electricity, I was intensely interested in the steam engine, and it will no doubt amuse Sir Charles Parsons to know that the first model steam engine that was given to me by my parents was a turbine. This turbine engine consisted of a rotating spherical glass boiler, from the upper part of which emerged a tube fitted with two oppositely pointing nozzles. It was filled with water and heated by a spirit lamp, and it worked as a repulsion turbine and ran quite nicely, but it did not appeal to me at all; personally I thought it a very poor thing. I turned all my attention and care to another model, which was given to me a little later on, and which appealed to me very much more, because it had a real cylinder and a real piston and went backwards and forwards as well as going round.

It was not until I was about eleven years old that I became in any way connected with electricity. I was then given by my parents a book known as "The Playbook of Science." This book was written by Prof. Pepper, of Polytechnic fame, and described all sorts of things, of a scientific nature, that were calculated to be interesting to the young. The first thing that appealed to me was the oxy-hydrogen flame or lime-light, which was described together with all the apparatus necessary to produce it. I remember talking to my father about this, and saying what a wonderful light it must be and how I should like to have the apparatus to make it. He told me that the electric arc-light was much better. This surprised me very much and set me thinking. The first thing I asked was: "How is electric light made?" My father said: "With a battery." I immediately thought of cannon and could not understand it at all, so I asked him: "What sort of battery?" and he said: "An electric battery." That did not carry me very much further, but it was really the first beginning of how electricity appealed to me. I have ventured to mention this, because it is often curious to see in what way people start out on different lines of work. The next book that I had was Ganot's "Physics." From Prof. Pepper's "Playbook of Science" and Ganot's "Physics" I think I obtained most of my technical knowledge. It must be remembered that in those days there was very little of a technical nature published, and it was exceedingly hard for the ordinary person to get information on any of these subjects. To show how curious this want of knowledge was, and how little one could see and know at the time—of course I am speaking of ordinary people, not such workers as Faraday and the other scientists, with whom one hardly came into contact at all—I conceived the idea of a magnetic engine which should work by the attraction and repulsion of permanent magnets. This involved the insulation of magnetism. Now, such a problem is very much the same thing as the problem of insulating gravity, which, if it were possible to accomplish it, would allow things to sail up in the air if they wanted to. I remember coming up to London from school one holiday and trying to find out what would insulate magnetism. I knew the sort of things that would insulate electricity. I went to an instrument-maker's shop near Long Acre. The head man was out, and there was a comparatively young fellow left in charge. I went straight to the point, and asked him if he could tell me if anything would insulate magnetism. He said he did not know for certain, so I asked him if he thought brass would insulate magnetism, and he said he thought it would. This sounds very silly, but it gives an idea of one's lines of thought in those days. If we think of a permanent-magnet engine working without apparent expenditure of power, it does not really seem much more wonderful than the idea of getting useful work from the dissociation of the atom.

About 1877, I had got on with my early electrical experiments, and had succeeded in making bichromate cells and an arc lamp. I had six bichromate cells, and the electrodes for my arc lamp were two lead pencils, such as are used in holders by draughtsmen. These tiny pencils, when carefully sharpened and brought into contact at their points, by the help of the bichromate battery gave the first small electric light that I was privileged to see. I need not say how much I thought of my first tiny electric light. A little later on I was fortunate enough to find a man who had made a dynamo. The machine which he had constructed and which I did not see working, was a shuttle-wound Siemens armature machine with a two-part commutator furnishing unidirectional current. This dynamo impressed me immensely. There was nothing very wonderful about it, yet I cannot say how greatly it inspired me. I remember going back and thinking about it, and going to bed and still thinking about it, and I found, when it was time to get up again, that I was still thinking about it and had forgotten altogether about anything else. I do not know why it had such an effect on me, unless it was, perhaps, that I had some instinct as to the wonderful things that would follow from the dynamo and motor. Then my first idea was to improve upon this dynamo. It is a very awkward sort of trouble, that, directly one sees a thing, one wants to make something better. It involves all sorts of difficulties, but nevertheless I set to work out what my idea of a machine was. I knew about the Gramme machine, although I had never seen one. I did not know about the Paccinotti, but I evolved, practically speaking, a Paccinotti machine, after a great deal of trouble, and after a great many delays, on account of the absorption of money caused in the process. However, the machine worked very well when I was able to drive it; and later on, the sale of this small machine when I had come upon hard times, tided me over until I was able to start earning for myself.

In 1878, I was again much impressed by what I saw in the way of electric lighting; I came up especially from the country to London to see the lighting of the Thames Embankment by Jablochkoff candles. Though I was not able to see the machines which produced the result, I was nevertheless immensely impressed with this first public demonstration of electric lighting. Later on I went to University College, and had what should have been the very great advantage of studying under Professor Carey Foster, Dr. Oliver Lodge (as he

then was), and Professor Alexander Kennedy. I always found it very difficult to learn, and I am afraid I learnt very little from these very good teachers. I was wanting the whole time to get on to something of a practical nature in the industry for myself. I am afraid that this interfered with everything else that I attempted to do.

A little later on, in 1881, I made two fruitless attempts to get into the Siemens Works. I considered I was likely to learn more there than anywhere else at the time. At the third attempt when I went to Mr. Alexander Siemens—and perhaps because I took an order with me as a sort of means of ingratiating myself with him—he gave me work at Charlton. I must be for ever thankful to him for this kindness. There I really got what I had been longing for. When I was at these works I was surrounded by dynamos and everything electrical, and had the desire of a lifetime satisfied. I felt entirely happy. This may seem strange to many who to-day are very much bothered with things electrical, and not at all sorry to get away from them for a change.

The position of electric lighting in those days was that many installations consisted of a dynamo supplying a single arc-lamp. There were, of course, at that time installations just beginning of Brush machines, supplying 16 arc lamps in series. The City of London, however, was so uncertain as to the best way to do its street lighting that it divided the contract between three concerns. There was the Brush Company, with a number of 16-lamp circuits; there was also the Maxim Company who used Weston machines, and who did, I think, very much the same sort of thing, and there was the Siemens installation consisting of a number of masts carrying very big lamps which were each fed from their own dynamos. The smaller streets were lit by means of alternating-current lamps with a few lamps on each circuit.

It is very difficult to know quite what to speak about and what to leave out. I think I must pass over the intervening period and say that in 1885 I had got to the point of taking out my first transformer patents. In 1886 there was a company which was endeavouring to light the West End of London by the Gaulard and Gibbs high-pressure alternating system. Great difficulties were experienced in starting this installation, and I was called in to try to get the company out of its difficulties. I cannot go into any details, but, as is now known, a considerable amount of work was done, resulting in what was then quite a big installation. We very soon were supplying some 30 000 lamps from this installation. In order, as I thought, to secure our position, because I aimed at lighting the whole of the north side of the Thames—an area similar to that of the Gas, Light & Coal Company—I had our mains run from the City in the East to Chelsea in the West, and from the Thames right up to the parts adjoining Hampstead. Then legislation came along and knocked this scheme on the head. The Government thought they knew much better how to do things and ordered otherwise. Our area was quite altered from that in which we set out to work, and our whole scheme was upset. I should like, however, to take this opportunity of calling attention to those devoted men who worked with me all through the difficult times in starting high-tension electric supply in London, and who gave of their best to help on that work to a successful issue.

The first to join me was your former President, Mr. Charles P. Sparks. After that, Lady Kelvin introduced to me her nephew, Mr. Vesey Brown. I do not know, but I think Mr. Sparks in those days was 21, and Mr. Brown younger still. They were followed by Mr. Arnott, who I believe afterwards became Chief Electrical Engineer to the City of Melbourne. Mr. Kolle, whom many of you know, Mr. Addenbrooke, who is here this afternoon, Mr. Reginald Wilson, Mr. Partridge (who has been good enough to bring these exhibits here this afternoon, which he will explain later); another of your Presidents, Mr. Wordingham, who has been with us during these meetings, although I do not think he is here this afternoon; Mr. d'Alton, and Mr. Hawtayne were also with us. There were very great difficulties to be faced in those days and great risks had to be taken in this new electrical work. Another member of the staff was Mr. Jacob—sitting on my left—who received a current at 10 000 volts through him without being killed.

I cannot let this opportunity pass without saying how deeply I appreciate the work of all these members of our Institution. They have contributed enormously to what advancement has been made.

I said I could not go into the question of the Deptford installation, and how we started with 10 000 volts. Even though my description might be short it would be too long. I should like, however, to say this, that our greatest difficulty in those days was not only the want of knowledge and the want of experience, but the complete lack of satisfactory insulating materials. We had to carry out a high-tension system; we had to build alternators; we had to build mains; we had to build transformers and we had to build switchgear, but the best materials that we had available were porcelain and ebonite. Whatever else was needed to complete the system we had to find and adapt, and so design gear that we could obtain the results with the only materials available. It is hard to think to-day what a handicap that really was, and it is interesting to know that such common things as brown paper and the refuse from making wax candles were used and enabled us to make mains which carried 10 000-volt current, and that many miles of these mains after all these years are still giving just as good service to-day.

I ought to finish, but I cannot do so without attacking my dear friend Colonel Crompton. He said, during the controversies that went on as between the advocates of alternating high-tension and direct low-tension current, the most shocking things, such as could not be repeated in a scientific meeting like this. He attacked me in every way he could, and on one occasion, I think, worked himself up sufficiently to threaten me with personal violence. But he fought fairly and, although hard hit, I recovered, and appreciated him more and more after each attack.

In 1910, I had the great honour of my life in being

elected President of this Institution. I found the Institution, as I thought at the time, wanting in life and usefulness to its members and likely to decline rather than develop. I saw what a great position the Institution might occupy and how much it could do for electrical science and for its members. I felt that what it wanted was life, and I tried to infuse that life into it. I pleaded for this and did everything I could, but really accomplished very little myself. Where I think I did succeed was in giving a lead to your Presidents who followed me; it was they who carried out the work of making the Institution the great Society that it is now known to be, and of which we are all proud of being members.

MR. F. BAILEY.

I should in the first place like to speak of the Telegraph Construction and Maintenance Co. which I joined in 1883, or 17 years after the completion of the Atlantic cable of 1868. All the cable pioneers were then alive and their great work had been fully recognized and appreciated as an example of the courage, enterprise, and determination which had made the British nation respected throughout the world. Submarine cables had then been laid to all parts of the world, connecting our colonies with the homeland and linking-up the British Empire.

The principal pioneers of the submarine cable became associated with the early days of electric lighting by the enterprise of the above Company in starting an electric lighting department—I allude to Sir John Pender, Sir Daniel Gooch, Sir J. Anderson, Mr. Henry Clifford, our Past President Mr. Willoughby Smith, and others. One penalty of working under them was the knowledge that they expected success and would not condone any failure.

Although I had nothing to do with the cable work of this Company, and am therefore not qualified to say anything about submarine cables, one could not be associated with the Company without a feeling of pride in its achievements and taking great interest in the stories told by staff and men of dangers and difficulties overcome in stormy seas, with the slender thread of the cable acting not as an anchor but as a precious connection with the distant shore.

These men deserve our grateful thanks, for they helped to form the Society of Telegraph Engineers, and there seems to be some danger of forgetting them in the ever-increasing activities and developments of the Institution. I must of course include in this reference the names of Sir Charles Bright and Sir Samuel Canning. Of the original band of heroes few now remain, but fortunately we still have with us Mr. F. R. Lucas, the managing director of the Company, who assisted in laying the 1865–6 cables from the giant and somewhat unwieldy s.s. "The Great Eastern," and who has since then laid many of the submarine cables of the world. During a recent visit to the works at Greenwich I was able to appreciate the remarkable skill with which they had been kept up to date by Mr. Lucas and his son.

My association with the late Mr. J. E. H. Gordon of the Telegraph Construction and Maintenance Co. lasted from 1883 to 1889, and I should like to pay some tribute to his remarkable mathematical abilities, his inventive genius, and the charm of his personality. He was not always understood by others and much of his work has been forgotten, but in the design of the Gordon alternator, and in the conception of the Gordon divided main, there are certain points of interest which may to-day be referred to as some illustration of the early difficulties.

The works at Greenwich had been equipped with a large Gordon flywheel alternator, and owing to no voltmeter being available—as nothing of this kind had then been made in a satisfactory form—the pressure of supply was regulated by a photometer which was placed in a dark room close to the engine, and the man sat near the stop valve of the exciter engine and kept his eye on the photometer.

Sir Daniel Gooch, chairman of the Great Western Railway Co. and also of the Telegraph Construction and Maintenance Co., arranged a contract for supplying electric light to the Railway from Westbourne Park to Paddington station, and the works were commenced in 1884 by placing the generating plant in a central position and using the Gordon divided main for transmission to the various local centres. There were three alternators, each connected direct to a compound engine made by Messrs. Rennie, these being the last engines constructed by this firm in London. In starting up these works in June 1885 it was soon found that the design required considerable alteration, as the engine indicated 600 h.p. when supplying only 4 arc lamps, and when in desperation I placed the machine on short-circuit the engine ran away. By alterations to the field-magnet poles, which were too wide, and also to the coils, we were soon able to obtain a better result and secured an efficiency of about 55 per cent.

As is well known, the Gordon alternator had two armature circuits, each entirely separate from the other, and as the number of armature coils was double that of the field poles the machine really gave two-phase current, the difficulty of regulation being overcome by cutting out coils on either phase—or circuits, as we then called them—and by means of a suitable switch placing these disconnected coils on short-circuit. Gordon had a strange belief in the use of solid iron cores and could not be induced for some years to adopt laminated cores, and he tried to reduce the heating of the solid cores by cutting slots in them. In the various books he wrote on the subject of electric lighting this point was mentioned, and his explanations would certainly have been revised if he had been able to carry out any revision of these books, but unfortunately his untimely death, caused by a fall from a horse, prevented these corrections being made. We had several coils constructed with slotted cores, but the change was not made until the works were taken over by the Railway Company, and then my chief assistant, Mr. A. H. Walton, had them constructed at the Swindon works of that Company.

The record of the output of these machines was obtained by the only instrument available at that time, namely a Siemens dynamometer, and although we knew that the machines gave a different result when supplying an inductive load, such as arc lamps with their choking coils, as compared with a similar load when supplying incandescent lamps, we had no knowledge of power factor, and this point was discussed with Lord Rayleigh and others who frequently visited the works.

The Gordon divided main requires some explanation, as it is not generally understood. During the winter of 1883–84 I carried out many experiments and tests in order to ascertain the effect of self-induction on the carrying capacity of wires of considerable length, and for this purpose we had the use of a large quantity of No. 20 wire which I placed on posts round a large field. The result of these tests was the development of the Gordon divided main, which consisted of a large number of small insulated wires all placed together in the same conduit, thus forming a multiple main, the size of these wires varying for the different centres of distribution from about 3/18 S.W.G. to 7/14 S.W.G., there being from 40 to 70 wires in each main, and as there were 4 mains to each district the total amount of wire was a considerable length—something like 300 miles. In addition to avoiding inductive troubles, this form of transmission main enabled us to vary the section according to the load and thus secure a constant drop in volts by adjusting the section of the cable. For this purpose a special regulator was constructed which varied the number of wires in circuit according to the load. We were thus able to adopt what is now known as the Kelvin law and to use the economic current density according to the cost of copper and coal, and in the case of Paddington this worked out at 1 200 amperes per square inch. This enabled us to use 150-volt lamps at the generating centre, 100-volt lamps at Westbourne Park, and 120-volt lamps at Paddington station.

After the first trials of this plant in 1885, complaints were received from the adjoining residential property of annoyance from smoke, smell, noise, and vibration. These complaints soon culminated in an action and injunction, and Mr. Justice North was so surprised at the extraordinary allegations made that he personally inspected the generating plant, and although he granted this injunction he gave time for certain alterations to be carried out. A writ of sequestration being applied for was refused, and when carried to the Appeal Court the application was dismissed. All the eminent counsel of the day were engaged in the case, and the Great Western Railway Co. had some difficulty in overcoming a troublesome point in the covenants of the lease under which they held the land from the Ecclesiastical Commissioners, as it was stipulated that no more than two stationary engines each of 16 h.p. should be placed on the land, and the Railway Company called in several experts, amongst them being Sir John Fowler, Sir Benjamin Baker, Dr. Hopkinson, Sir F. Abel, and Sir F. Bramwell.

The works were therefore shut down until April 1886, when the contract-running definitely commenced. The works were taken over by the Great Western Railway Co. in the following year. During this interval tall chimney shafts were erected, the steam was condensed, and various alterations were carried out in the generators to reduce noise and heat. The insulation of some of the divided mains had given trouble owing to the hot-water discharge from the locomotive injectors which sometimes stood for long periods on the line, and thus allowed the hot water to accumulate and heat up the mains. Mr. Willoughby Smith, who was then manager of the Wharf-road gutta-percha works of the Telegraph Construction Co., resented any criticism on the use of gutta-percha as a suitable insulator, and expressed his opinion that any insulated conductor would break down under what he called an "over tension" due to the use of reverse currents. The breakdown of one complete feeder caused some consternation to the board of directors, and the fate of this enterprise was in jeopardy. I was requested to attend the board meeting and had to plead very hard to avert the abandonment of the whole scheme, as the board thought that the plant could not work more than one year. I gave a confident promise that it would work at least 20 years, and fortunately this promise was more than fulfilled, the works being finally demolished in 1908 when the site was required for extensions of railway lines, and it was then possible to transfer the load to the new power station at Park Royal. The final compliment paid to this plant was an efficiency test carried out by Sir Alexander Kennedy and Mr. Roger Smith, when it was found that the plant gave an efficiency of 73 per cent with 41 lb. of water per kilowatt-hour, the engines running at a speed of 157 r.p.m., thus giving a frequency of 36 per second. Mr. Roger Smith has placed all details of this test at the disposal of the Institution, and I have had great pleasure in sending him all my records of the early tests and difficulties.

It is difficult at this date to realize the condition of electrical work at that time. The abortive Chamberlain Act of 1882 suggested a recognition of the possibilities of electric lighting, only to kill them by very limited encouragement. A Select Committee of the House of Lords, with Lord Camperdown as chairman, sat for 9 days taking evidence which emphasized that the state of electrical science was not then satisfactory for investment of capital, and two large corporations sent their town clerks to protest against further concessions to electric lighting as they had bought up the local gas works—in one case paying £2 000 000 for them. Sir George Elliott, M.P., told me at that time it was hopeless to expect Parliament to foster a rival to gas, but fortunately, as we all know, the 1888 Act was passed and assisted progress, but in a limited parochial manner. Members of the House of Lords Committee visited Paddington, and the witnesses were frequently referred to the success of this demonstration as a proof of the practical possibility of general distribution.

By hard and continuous work we were able to convert the threatened failure into a practical success, and as engineer in charge of the undertaking I have to acknowledge the valuable work done by Mr. A. H. Walton,

Mr. C. A. Holbrow, and Mr. W. M. Meredith. Mr. Walton remained at the works for the Great Western Railway Co. for a few years; Mr. Holbrow joined me at Whitehall after we had started the Whitehall Electric Supply Co.; and Mr. Meredith went at our request to Mr. Howell's battery works at Llanelly, where he was developing a promising type of solid-plate secondary battery.

During arduous, and sometimes exhausting, work in connection with this enterprise I utilized any spare time in trying to evolve an experimental single-phase induction motor, and also a two-phase rotating-field motor, using a synchronous motor to drive a commutator in the hope of rectifying the current, but owing to the constantly varying power factor of the circuits I was not able to obtain a satisfactory result.

During the litigation I made a friendship with Dr. John Hopkinson which lasted until his lamented death. He gave me useful information regarding improvements in these generators, and also drew my attention to his Patent No. 3 362 of 3rd August, 1881, in which he described an adjustable self-induction coil which would have made an admirable transformer.

In 1887–8 we carried out a direct-current station at Whitehall, and with the consent of the St. Martin's Vestry laid mains (Messrs. Callenders being our contractors) up to St. Martin's Church and on to the Garrick Theatre, and then to Messrs. Hamptons along the front of the National Gallery. We had deposited a Bill to obtain the necessary Parliamentary powers, and this was made an Act in 1889. The Garrick Theatre, which was then being opened, was supplied from a separate battery in the rear of the premises; and we carried out the lighting of St. Martin's Church with some interesting episodes, for I obtained some old oak which had been stored in the crypt for many years and asked Mr. F. H. Nalder to work it up for us for switch blocks, with the result that his men spoilt both their tools and their temper in attempting to work on such hard and unkind material.

It was difficult, even in 1888, to obtain a satisfactory direct-current dynamo of 100 kW output, and our first machines were a failure and had to be replaced. Howell batteries were put in as an experiment, but soon failed, as the plates either buckled or expanded, breaking the jars and causing the acid to short-circuit the whole thing with a wonderful display of fireworks. We put in three Willans engines of the then new central-valve type, these engines being the first to have the solid crank-pin eccentric, as the separate keyed-on eccentric used at Vienna had not proved satisfactory.

Our work in Whitehall Court was interesting, and included contracts for providing elevators, fire service, water-softening plant, hot and cold water services, electric lighting, etc., all the pumping work being done from the station, and the hot water for 100 bath-rooms, kitchens, and corridors, etc., was obtained from the exhaust steam by the use of a large Berryman heater; and for many years the whole of these supplies were carried on without a hitch.

These works were then absorbed by the then newly-formed Metropolitan Electric Supply Company, with Sir John Pender as chairman, and some old friends from the Telegraph Construction Co. as directors. I was appointed their engineer in August 1889, and Mr. Gordon started practice as consulting engineer, but he also took some unfortunate risks in connection with contracting work which involved him in financial loss.

For the next 6 years we had a constant struggle against all kinds of difficulties, and erected plant in four other stations, all of which gave more or less trouble, either in operating the plant or in fighting injunctions for vibration, etc.

The works at Sardinia-street were started at the end of 1889 with Westinghouse plant, single-phase, 1 000 volts, 133 frequency, and 50-volt transformers, overhead mains being used until we had time to lay underground mains. To avoid induction troubles, all mains were grouped together and drawn into cast-iron pipes, and, although the alternators did not work in parallel, no trouble was caused by phasing induction. All the mains were 7/16 S.W.G. with vulcanized rubber insulation of Silvertown make, and to avoid joints in the street I adopted a looping system so that every consumer had the benefit of a ring main, and we could connect a new consumer without interrupting the supply. During the next 7 years this system was extended in all districts, and a large quantity of this cable was obtained from Silvertown and ran without a single failure in insulation.

Complaints were soon made of annoyance from noise and vibration, and after purchasing a public house which complained of loss of trade owing to the noise or the vibration causing the beer to become cloudy, we were left with a long-continued bombardment from the adjoining solicitors' offices in Lincoln's Inn Fields, but these never culminated in an action for injunction, thus showing the wisdom of the law in not taking the risk of a legal action.

An artesian well was sunk on the premises and a good supply was obtained for a short time, until we dislodged some Thanet sand which caused serious trouble with the pump buckets and valves, etc. We therefore sank the well a little deeper and obtained salt water. After running many years these works were acquired by the London County Council who required the site for the construction of the new street now called Kingsway.

At this station we made our first trial of oil fuel, using green oil from the gas works. The result was not altogether favourable, as we emitted black smoke from our chimney shaft, and the powerful odour of the oil occasioned some criticism. Eventually, we augmented the plant at this station by Parsons steam turbines.

In 1891 the engine-room of these works was destroyed by fire; but the Westinghouse Co. quickly replaced the plant by improved machines, and we had the benefit of comparing American practice with our other stations then running with English plant. There were such constant changes in the personnel of the Westinghouse Co. at that time that we were fortunate in having one continuous and able representative of the company in Mr. O. H. Baldwin.

The Drury Lane Theatre was anxious to obtain a supply in the winter of 1889 and, as we could not

complete the laying of the underground mains in time for the pantomime, the first supply was given by means of overhead mains. Sir Augustus Harris was so pleased with the opportunity of adopting novel stage effects that he tried to dress the ballet with incandescent lamps, but the heat given off by the lamps, at 4 watts per candle, was so great that the rehearsal produced a dance of agony and the victims objected to being grilled.

The Holborn Restaurant also urged us to connect them up, as their own private plant was giving trouble, and as they required 100 volts we had to place the Westinghouse transformers two in series, and required about 52 transformers for their full supply. The building had been wired using two Edison **D**-shaped conductors in one tube and, as one of these tubes suffered from a short-circuit, they had made the whole of one tube the positive connection, using another tube as the negative connection, but there was no evidence of this change at the switchboard, and not knowing that any change had been made we connected up in the usual way, and were surprised to receive a message from these customers that they "wished us to supply light, and not music." Their complaint was justified, as the iron pipe caused a heavy inductive drop and emitted a penetrating musical note.

The Rathbone-place works were started in 1890, using Babcock boilers, Willans engines, and Parker alternators of 100 kW each. This station worked well for about 16 years.

The Manchester-square works were also started in 1890 with a similar plant, but with 5 years' anxiety owing to vibration troubles. Complaints were soon received from adjoining residents of noise and vibration. At this time none of the Parker alternators would work in parallel, and a system of changing over circuits had to be adopted, but the noise was difficult to control, as the sound waves varied in amplitude as the machines varied in speed, and varied from quick waves to a prolonged drone. Many attempts were made to mitigate the vibration, but on examination it was found that the site covered the original course of the Tyburn Brook, and the subsoil, while apparently firm on the surface, soon developed into a muddy silt and we did not reach clay until we bored down from 30 to 40 feet. These borings were made through cast-iron cylinders of about 3 ft. diameter, the lower cylinder being provided with a cutting edge. A large number of these piers were bored through the existing foundations with lateral columns, the base being excavated to form a heavy shoe, and the whole of the columns were filled in with concrete. The Willans engines, however, still continued to give annoyance to the neighbours, and, although the applications for an injunction were suspended from time to time, the judge finally intimated that some drastic cure must be adopted. Sir Charles Parsons then offered to construct turbines of the then unknown output of 350 kW and a large number of these machines were ordered. The anxieties of maintaining the supply under these conditions were very great, and the preparation of affidavits necessitated frequent journeys to Newcastle, with a rush to write the affidavit and get it sworn in time for the court in order to secure a further suspension of the injunction.

In these early turbines the armature was the rotor, and fortunately they worked with a great reduction in the humming noise and a freedom from vibration. I do not like to refer to the many breakdowns of this plant, as they were obviously inevitable in the early trials of such a large departure from existing practice, and our gratitude at being saved from the ruin of an injunction enabled us to praise even the most defective turbine.

After this experience Messrs. Parsons were able to build even larger turbines with a remarkable freedom from stripping and fractures, as everything that could break down had already done so at these works.

The test taken by our superintendent, Mr. Holbrow, on these turbines gave a steam consumption of 52 lb. of water per kilowatt-hour non-condensing.

As indicating the limitations of turbine design about this period, Messrs. Parsons offered to construct a turbine giving 500 kW, and, desiring to adopt another design of alternator, I arranged with Messrs. Parsons to construct the turbine and for the alternator to be made by another firm, with the result that after efforts extending over some years every machine was a failure and we were asked to cancel the order. Messrs. Parsons thereupon completed the alternators, and they are still running.

The Amberley-road works commenced to run in 1901, using plant supplied by Messrs. Johnson & Phillips consisting of Hornsby locomotive boilers and horizontal engines with Kapp rope-driven alternators. These locomotive boilers were soon afterwards changed to Babcock boilers, and the rope-driven plant worked for many years without any trouble, and was exhaustively tested by our then superintendent of the works, Mr. R. A. Chattock, the steam consumption being 56 lb. per kilowatt-hour non-condensing, and the thermal efficiency of the plant about 4 per cent.

During all these anxious times, the cheery optimism of the chairman of the company, Sir John Pender, carried us through many difficulties, and he was always pleased to discuss any matter, particularly at breakfast, as he appreciated the advantage of catching one's fish early, getting him fresh, and having him for breakfast.

The Willesden site was then purchased, and I sent out specifications for the plant in June 1897, the works being started about 1900. At that time no English maker submitted an offer to supply three-phase plant, and Dr. John Hopkinson advised me not to take the risk of such a new departure, while Lord Kelvin protested that I was unwise in going for such a large machine as 1 500 kW, as he thought 500 kW was a much safer size. The Westinghouse Company undertook, however, to repeat a successful example of a two-phase machine of 1 500 kW.

In 1895 I was invited to become Engineer-in-Chief of the City of London Electric Lighting Co. Feeling that a multitude of worries would cancel out, I took up this work, and may briefly refer to some of the early history of this Company.

The capital required for the pioneering work of the City Company was difficult to obtain, as the prospects were considered problematical and the investing public

had no confidence in electrical undertakings at this time. Mr. J. B. Braithwaite therefore secured the support of Messrs. Rothschild, and difficult technical progress was therefore successfully financed. The contracts for the supply of plant were given out to the specifications of the late General Webber, who was then engineer to the company, and he was assisted by Mr. G. H. Nisbett and Mr. F. H. Jackson

The Brush Co. supplied engines of the marine type driving alternators of 400 to 500 kW; and the Thomson-Houston Co., through the Laing, Wharton & Down Syndicate, supplied Willans engines and Thomson-Houston alternators of 400 kW each. In the first set Willans, having some difficulty in making an engine of this size, supplied two engines to drive one alternator, with a magnetic clutch (which did not work well) connecting the second engine. This part of the plant worked well for a number of years, the success being largely due to the efforts of Sir (then Mr.) James Devonshire and Mr. A. L. C. Fell, who, with the assistance of Mr. Grove (later of the Central London tube and now of Australia) and a young pupil named Mr. C. H. Merz, succeeded in making the plant work well in parallel in spite of the large amount of iron in the armatures; and there was no difficulty also in running it in parallel with the former pioneering works at Wool Quay at a distance of about one mile.

The Brush plant was well constructed, but the armature coils were a failure and we secured the assistance of Mr. Ferranti in applying his corrugated coil, which was such a marvel of construction.

The steam consumption of the Willans engines was about 26 lb. per kilowatt-hour condensing, the Brush plant with Ferranti coils working out at about 42 lb. per kilowatt-hour.

In 1895 we erected the first Ferranti switchboard, many parts of this board being still in operation without a single failure.

In 1898 we commenced to run the first Ferranti engine with tripping spring valve-gear. This engine gave 1 500 kW, and it was soon found to work better with a direct-driven valve, but the engine rocked considerably and caused enough vibration to remove the statue of St. George and the Dragon, which at that time was placed on the front of the main building, and we remarked at the time that Ferranti had killed the dragon but his engine had destroyed the horse.

A brief reference to distribution may perhaps be excused, as considerable history was made about the year 1893, when the late Mr. J. B. Atherton acquired Riddies' patent No. 11 894 of 1884 for the use of spirally-wound paper cable, this patent also introducing a reference to concentric conductors.

Mr. Nisbett informs me that the first triple-concentric paper cable was supplied in 1893, and only just in time to avert a serious calamity, for Mr. Peard of the City Company, testing the pressure of supply at the end of a comparatively short distributing main, found that the drop was much greater than could be accounted for by ohmic resistance. Further tests on other mains revealed a drop of up to 20 per cent, and it became necessary to overhaul the whole system; and it finally resulted in the separate single cables being discarded for alternating-current distribution.

Mr. Nisbett then worked out a complete set of joint boxes for the triple-concentric cables, and on comparing this progress with that in other countries, I think it is quite clear that we owe an important development to Mr. Nisbett.

The design and manufacture of concentric cables was rapidly improved, Mr. Ferranti being entitled to the credit of adopting segments instead of wires for the outers of concentric cables.

I am informed by Mr. Nisbett that the first paper cable made in this country was supplied to Mr. Gordon for his work at Bray in Ireland.

In conclusion, I should like to bear testimony to the extraordinary devotion to duty shown by engineers in charge of electrical plant and public supply. Having been associated with a large number, it is surprising to find how much skill is shown by them in carrying out the most difficult tasks, and so long as this high grade is maintained there can be no fear regarding the future of electricity supply.

SIR THOMAS O. CALLENDER.

I come before those present here to-night with great diffidence and with considerable doubt as to whether I can say anything about my experience in the very early days of electric supply which will be of interest. On the other hand I am consoled somewhat by the fact that this same diffidence seems to have struck my old friend, Dr. Ferranti. I hope it is a sign of modesty of the early pioneers.

It is a difficult matter to recall valuable or interesting information when I look back on the 40 long years which have passed since I first put my hand to electrical work. Such a period is a long spell out of a man's life, and it has been a busy spell for the industry and for me. I find that, just before I took an active interest in electrical enterprise, my first experience was in St. Petersburg. I was in Russia on quite different business, and my friends said: "You must come to the Opera to-night, because there is a big show on and it is being lit by electric candles." I suppose it was about 1880. I went there, and the lighting was very fine, partly by immense numbers of wax candles, the State wax candles of the old Empire of Russia, and partly by a host of Jablochkoff lights.

Soon after coming back to England I went to the United States, also on other business, in one of the old Cunard ships lighted by oil lamps such as had been doing duty for generations, and it made the crowded ship both smelly and uncomfortable. Coming back I was a passenger on the "Servia," which was, if not the first vessel to cross the Atlantic with electric light, certainly the first large liner to have an effective installation. The day before we sailed there was a great reception. Crowds of people came on board to see this wonderful ship which was lit by electricity. It was there that I first met Mr. J. F. Allbright, who was, as is known, intimately associated with the original

Edison Co., and later with Col. Crompton's firm. Allbright was the engineer-electrician in charge, and from that time began a friendship which lasted until his death.

Shortly after that I myself played with electricity. The investigations which we had made in connection with our bitumen business showed us the possibilities of using it as an insulator. Our patent was taken out, and in 1882 we formed our Company, which was carried on by my father, my brother, and myself, in conjunction with old Telegraph Construction and Maintenance men, Sir Samuel Canning and Mr. Robert Sabine (both Atlantic Cable pioneers). Looking back on the records I find that among the first people with whom we did business in 1882 and 1883 were our friends Bernard Drake and Col. Crompton. We, like others, started in a small way, on private house installations. I heard from Mr. Drake some time ago that some of those early installations were still running well. An early installation was that put in Buckingham Palace. In conjunction with Mr. Massey, of Twyford, we laid a number of heavy mains there, which existed until the Palace was supplied in another way. The heavy feeders for the lighting of Victoria Station were also laid about that time for Col. Crompton's Company. In 1883 we did a lot of work for the Jablochkoff Company for the Covent Garden Promenade Concerts and the preliminary lighting of part of the Victoria Embankment. Among those associated with that work was my friend Mr. Reeves.

Shortly afterwards I was again in Russia, and, whilst at the frontier, was, with other travellers, badly treated by the Customs officials. They gave me a great deal of attention. The man examined after me, a Russian, also got into trouble. On his name being called I learnt that it was Jablochkoff. He and I finished the journey together, and from that time became friends.

The first real business in public supply we had in this country was for the Chelsea Electric Supply Company. That Company was the real pioneer of electric supply with underground mains in England on modern lines. The Grosvenor Gallery system was earlier, but the first Company that entered seriously into the field of supplying electric light in London on what I may call orthodox lines, with the necessary Provisional Order and all the other hindrances that the Government put upon us, was the Chelsea Company. Major-General Webber was its moving spirit. The difficulty that Company met with was not so much an engineering difficulty as a financial one. It was impossible to get people to back up electric light with hard money. The Company endeavoured to supply a rich neighbourhood, where there was plenty of money and great desire for the light, and yet we could not get enough financial support. It finally ended in that Company being financed very largely by my own Company, and by the Electric Construction Co., and the Electrical Power Storage Company with Mr. King's help and on the system with which his name is identified. I venture to think that that pioneer station had no small effect in helping forward electricity supply in this country. It was run on the direct-current system, with large storage batteries in sub-stations, and has continued largely on the old lines. It is still an independent Company, but I assume it may be absorbed in the great general scheme which will be shortly introduced for London.

I had also some very interesting work for the Company to which Mr. Bailey has referred—the Whitehall Court—for which many underground cables were laid. We also ran a series of mains round Charing Cross and the Strand for the Company promoted by Messrs. Gatti, with Mr. Patchell as engineer. That Company had then no legal rights to do so; we had no powers; we had simply permission from the Vestry to dig; I was told I had to get the work done somehow, and we did it; we pulled roads up and nobody interfered. It was very curious in those days; no end of people wanted to know what was being done, and instructions were given that they were not to be told. So they were not told. The engineer whom I had in charge was discretion itself, and he spun suitable yarns which were interesting and fanciful, with the result that nobody quite understood why the trench was open. One day, while we were at work in front of the National Gallery, Sir William Preece (Mr. Preece, as he then was) asked me to come and see him. There were no telephones in those days. I went, and he said: "Look here, Callender, you have a very clever man doing that job of yours by the National Gallery." I said, "What job?" He said, "That's all right. I saw some of your cables. Don't worry, but do tell your man not to say it is Post Office work." I said, "What has he been telling you?" He said, "Well, he put it in this way. I asked him and he would not tell me anything. So I said, 'Is it Post Office work—Post Office Telegraphs?'—and he took me by the lapel of my coat and said, 'Ah, now you have it, but don't tell anybody.'"

That was one of the ways in which we did things in those days. We laid many miles of cable and very seldom were we challenged. It was necessary to make arrangements with the local authorities and obtain their permission, but they used to give us those permissions with considerable misgiving and much reservation. It did not matter; sometimes we got them and sometimes we did not, but the work went on just the same. I remember on one occasion the Company—now the Charing Cross Company—required to lay mains across to Lambeth. We carefully considered our procedure, and came to the conclusion that the only way to do it was on the Saturday before the August Bank Holiday, because the Courts were closed then and no one could get an injunction. I had everything ready, and some hundreds of men waiting, and at 3 o'clock on the Saturday afternoon we swooped down on the streets. On the August Bank Holiday, the telegraph having been put in motion, some person from one of the interested authorities came up to know what we were doing, but of course nobody could tell him. All we could say was we were going ahead. We got the mains into Gatti's works on the south side of the river on Tuesday morning, with the cables laid and the paving replaced. Then questions arose as to what the authorities would do. We did not worry; we simply let

matters drift. We had a number of threatening letters. I think I was going to be hauled up for contempt of Court or something of that kind. In the end nothing happened. Some time afterwards the Charing Cross Company regularized their position by obtaining the necessary Provisional Order, but the mains then scheduled had been laid for years. Those were the days when it was necessary to take a strong line sometimes. I am sure that, had we waited for permission, a good deal of lighting in London would not have been done until many years afterwards.

There is one little interesting experience I should like to refer to with regard to Mr. Willoughby Smith of the Telegraph Construction and Maintenance Co. Years after the electric station at Paddington had been running alterations had to be made to the cables on account of permanent-way changes. We carried out that work, and I heard nothing more of it until last year when on my way to India. When some days out from Marseilles one of my fellow-passengers came and said: "You are Tom Callender, are you not? My name is Meredith. When you did that job on the Great Western Railway at Paddington I was one of the engineers in charge." We then forgathered and told each other many reminiscences of much of what had happened. Later on that day another man came up and said: "You are Tom Callender? I have a letter of introduction to you. My name is Willoughby Smith." We forgathered, as is customary on board ship in the orthodox way, and we told one another stories also in the usual way. In the course of our conversation I said: "Do you know there is one of your men, named Meredith, on board?" He said: "No, I have not seen him for twenty years"; so I got hold of Meredith, and the three of us met there at sea in the Mediterranean, not having seen each other I suppose for twenty years or thereabouts: the man who represented the Company, the man who was in charge of the work, and the man who did the work. It was one of those curious combinations in which chance sometimes throws people together.

My time has now run out, so I will only briefly record that I have been connected with the lighting of Liverpool since its very inception. I remember the original generating station at Rose-street, which was about one-quarter the size of our Lecture Theatre. Holmes and Vaudrey, well known in connection with Liverpool, started a few years afterwards the Birmingham Electricity Supply Company, but very little support in Birmingham was then obtainable for the electric light. It was therefore necessary for my Company to take a considerable number of the shares. Had it not been for that and for the loyal assistance which we received from Messrs. Bolton, of Oakamoor, who were always ready to help electrical enterprises in the early days, that installation at Birmingham would not have been brought into existence until years later.

It is extraordinary to think what difficulties we had in starting electricity supply in this country. It was not so much a question of engineering troubles; the great difficulty was, as before mentioned, to arrange finance to carry the work through. That is one of the things which, fortunately, those gentlemen who are coming on now to undertake new enterprises will not experience. Of all the worries it is possible to have, there is, I believe, nothing so bad as being short of the necessary funds, and to recognize that excellent profitable business is strangled for want of money, I trust, however, that the greater confidence in the industry has put an end to that anxiety.

MR. J. SWINBURNE, F.R.S.

In looking back more than 40 years it is very surprising to realize our extraordinary ignorance in old days. I began electric work in the autumn of 1881. The old idea that there was some curious problem awaiting solution called the "Subdivision of the Electric Light" was still rampant. It must be remembered that the dynamos on the market were series wound. Compound winding was unknown, and shunt winding was a mystery jealously guarded by one maker. The "Electric Light" was an arc lamp. Generally each lamp needed a dynamo, and the dynamos were series wound with drooping characteristics, because they were badly designed. The drooping curve was a case of beneficent ignorance. The problem was to make one dynamo run a number of small lamps. Jablochkoff, for example, ran four armature circuits on a two-phase alternator with several of his candles on each.

In December, 1881, I went to Antwerp with Mr. C. F. Proctor, to make some Swan lamps to prove the working of the Belgian patent. Facilities were given by the owner of a wood-sawmill. We made one lamp. One leg of the carbon was broken, and patched up with fine copper wire. It cost nearly £100. The proprietor of the sawmill asked us to light his house, which was joined on to the mill. We led plain copper wire, stapled to the woodwork of the mill buildings, from the dynamo to the house. Inside the house the owner did not want his plaster walls injured. We therefore drove in small tinned tacks, and carried pairs of small green silk-covered wire to the lamps, giving each pair a turn round a supporting tack at convenient intervals. There was trouble in starting this installation. I knew nothing of the theory of dynamos; and there were no rational textbooks, and no measuring instruments. I got a French treatise on dynamos by a man who was a great authority in those days, but found his mathematics were mixed. I found that the dynamo was less wild in its behaviour when heavily loaded with iron wire; using a touch of a lamp as a voltmeter. I therefore put on an overload of iron resistance, and the lamps, and reduced the load till the lamps were right. In spite of this the installation was not a success according to modern ideas. The speed of the Gramme varied enormously with the sawmill load, and the wires short-circuited promiscuously where wound round the tacks. I went to the expense of a double set of tacks, positive and negative tacks; but the dynamo speed problem was left unsolved.

From Antwerp we went to Paris, to start a Swan lamp works. We had many difficulties. A shunt dynamo was ordered from Siemens. It came—very late—and wound wrong, the shunt wire being far too large. I therefore made two of the four coils into a shunt circuit, with iron wire in series; the other two were put in the main circuit with iron wire in shunt to them. In this way a real compound dynamo was obtained, which ran the pump-room. I believe this was the first constant-pressure dynamo ever put to work; but I am not sure. The idea, however, was known to some before this date.

I remember buying an engine. The French did not understand cheques at that time; and a man came with a leather bag to collect the cash in accordance with a written request that I should "Upset the money among his hands." When the engine had been erected, we could not get it started, though we were hard pressed as to time. After a few days' unaccountable inactivity we were invited to the engine-room. The engine was covered with flowers, and there was a bouquet for me; the men were in holiday garb with carafes of wine; and we had to drink the engine's health, and close down for the day. Next day the engine was at work.

In 1881 we had no practical measuring instruments. The best were wooden electro-dynamometers which had to be adjusted to zero to get a reading, reference to a table giving the current in alleged "webers." Voltmeters could be got in many weeks, by ordering them, but they were wound with copper wire. As the power wasted by either instrument was comparable with that used by the lamp, a calculation was always necessary to get rational results.

The earliest suggestion of carbon incandescent in a vacuum was in Belgium in 1836, the object being a safety lamp for mines. About 1878 Swan was experimenting on carbon lamps; and Edison was working at lamps and the "subdivision." Swan made the first lamp; but Edison realized that the lamps must be of high resistance arranged in parallel. The very early lamps had conductors of paper, or bamboo. The material was neither durable nor uniform. Swan introduced parchmentized cotton, which was less irregular and better. We owe the homogeneous cellulose to Weston of instrument fame. Flashing under low pressure was also due to Weston. Then Swan invented squirting. Squirted zinc-chloride solution of cotton was due to L. S. Powell. Squirted viscose was worked out by C. H. Stearn at my suggestion. When he had succeeded in making viscose filaments he brought me a reel. I urged him to go much farther and see if he could make artificial silk, then made from pyroxylin by the Swan or Chardonnet process. In a few months Stearn brought a hank of beautiful viscose silk. I think this was the first viscose silk ever made, but I am not sure.

The carbon filament was rivalled by osmium, worked out by von Welsbach of gas mantle fame. Osmium is dear, and the lamps had low resistances. Next came the Nernst, and the tantalum (Siemens). The tungsten lamp holds the field now; and the greatest jump forward has been made by Langmuir, in the gas-filled lamp.

Looking back over the last 40 years one's main reflection is that the giants of old were really rather pygmic. We have now an industry employing thousands of trained minds and a large number of scientific and business men of exceptional ability; and we handle money by the million. It is therefore exceedingly difficult to rise to the top. Forty years ago there was merely a beginning. The able men of the world were generally engaged doing big things in existing industries. The electricians of that day were largely telegraph people whose equipment was not suitable for developing a new industry, science masters and inventive enthu aiasts with rather little knowledge. To appreciate this a study of the proceedings of the Institution during these early times is enough. It was fairly easy to rise high in the industry then, and having done so, to keep a reputation in spite of the growth of a large profession of highly trained younger men. This does not mean that all the older men who have reputations do not deserve them; many have kept abreast or in the front rank in some branch of industry or science; and would have risen to their present positions even if they had started later.

One cause of the different mental equipment of the electrical engineer of to-day and of 40 years ago is the advance in real education. Matters that were very difficult to understand in the early 'eighties are now quite elementary. Thus about 1884 Hopkinson called attention to the fact that the product of the volts and amperes in an alternate-current circuit is not necessarily the watts. I remember they had an alternator at Brighton, and they tried it on some inductive circuit and found the indicator diagram smaller than the apparent watts warranted. Someone told one of our esteemed past-presidents of this. He regarded his informant severely but thoughtfully for a few moments, and said, "You're a liar."

I have already mentioned the poverty of good textbooks. The electrical and engineering papers, not to speak of the Institution, were enterprising and did much of great value. The *Electrician*, edited by Mr. C. H. W. Biggs, and the *Electrical Review*, by Messrs. Alabaster, Gatehouse, and Kempe did splendid work.

The blight due to the action of the local authorities and Government is a branch of history that will, no doubt, be discussed by others. Belief in Government and Government officials is, as Spencer pointed out, a kind of fetish. It has come down from the savage times of the tribes, and remains with us because we still retain, thinly disguised, much of our original savage nature.

MR. W. H. PATCHELL.

STORAGE BATTERIES.

A monograph on the progress in secondary batteries for 50 years can touch only the high spots and must leave a great deal unsaid. For the greater part of the time the changes were rung almost exclusively on the lead-sulphuric acid battery.

In 1860 Gaston Planté introduced his lead-plate battery in which the surfaces of the plates or sheets were "formed" into active material, and from 1870 onwards his cells were regularly used for surgical and other purposes where small, steady currents were required.

In 1880 Camille Faure introduced the coated or pasted type of plate. The following year brought publicity and gave a real impetus to the business. The cells are described as being made up of 2 lead plates for each element, covered with red lead or other insoluble oxide of lead, surrounded with a felt partition kept in place with rivets of lead, and placed close together in acidulated water. The plates, if long, were rolled in a spiral. It was 4 elements of this type in one box which Sir William Thomson's friend brought over to him in Edinburgh from Faure in Paris in May, 1881, the report on which Sir William sent to *The Times* of 8th June, 1881. He called it a "marvellous box of electricity" of about 1 ft. cube weighing 75 kg and containing 1 000 000 ft.-lb. of energy. Some people had a vision of electricity being delivered like milk from house to house. Sir William saw farther than that. His scheme, sketched in his British Association Lecture in September of that year, included a transmission from Niagara of power at 80 000 volts, charging a Faure battery of 40 000 cells which would be discharged in groups of 50 removed from the circuit by methodical means.

Professor Adams first showed Faure cells in England at the King's College soirée in July, 1881, when 20 Swan lamps were run off 44 cells, and in the following October Radcliff Ward had the first temporary lighting show of 15 lamps off 40 Faure cells, 15 in. × 9 in. × 4 in., at the Junior Carlton Club.

By the end of the year Faure's discovery of an "accumulator of boundless power" was found to be rather short of the anticipated success as the felt wore into holes and metallic lead formed between the plates and short-circuited them. What an epitome of the art!

In 1882 the Electrical Power Storage Co. was formed to work the patents of Faure, Sellon, Swan (to whom the plate with pellets is due) and others, and in the following year Prof. (now Sir) Oliver Lodge exhibited specimens and details of their cells at his Cantor Lecture. The large plates were 9 in. × 10 in., and the small ones $7\frac{1}{4}$ in. × $5\frac{1}{2}$ in. The plates were separated by india-rubber plugs, and were stood on wood blocks to keep them clear of the bottom of the boxes: the lugs were bolted together.

In 1885 the Electrical Power Storage Co., then under the guidance of Messrs. Bernard Drake and John M. Gorham, took the only Gold Medal for Improvements in Secondary Batteries at the Inventions Exhibition.

When I took over the management of the E.P.S. Works at Millwall from Mr. J. M. Gorham in 1886 I found that developments had been made to encourage the use of storage batteries along the lines of private plants for mansions, banks, etc., and for tram-cars, motor launches and railway lighting. A branch of the business then important but now defunct was the temporary lighting of large private houses for balls, etc. Carlton House-terrace, Grosvenor-square and similar districts provided good customers before public supplies were available. The peak load occurred at the Jubilee celebration when every acid-tight box and every plate that could be relied on to discharge were sent up to the City or the West End.

The store or dump for "chills," in which the lead grids for plates were cast, was interesting as it showed that there had been giants as well as pygmies in those early days. While the sizes then commonly used were much as at present, there were chills for plates 21 inches high × 15 inches wide (anticipating central-station plates) and at the other end of the scale "fairy" plates $2\frac{3}{8}$ in. × $3\frac{3}{8}$ in. Arrangements of pellets and shelves of all shapes and sizes could be found, as well as conical plates, trays, and other curious conceptions. Grids were at first made of pure lead, but later various percentages of antimonial lead were used. They were pasted by hand and lead-burned to a strip of heavy sheet lead into sections. "Casting" into sections was adopted some years later at Millwall. The ordinary form of separator was still rubber plugs. We had also tried or were trying fluted and plain biscuit-ware, lattice work, matting, and grids. Hair-pin forks, first of ebonite, subsequently of celluloid, and glass rods came later. Container boxes were of glass for stationary batteries, and wood lead-lined, or ebonite, for portable work. Railway lighting and traction cells were hermetically sealed until the bursting of lids called for ventilation.

About this time Messrs. Elwell-Parker started manufacturing Planté cells, but later changed to the pasted plate. I believe the casting of the plates into sections was due to Mr. Thomas Parker's training and skill as a foundry worker.

The absorption of the E.P.S. Co. in 1889 for the sake of some traction patents by the Electric Construction Co. who had bought up Elwell-Parker and intended to develop traction work brought in new interests but restricted the E.P.S. Co. to battery work. Meantime a special line of central station work was being developed and was adopted by the Chelsea Electricity Supply Co. Large batteries were charged in series and discharged in parallel on elaborated B.T.K.* patents. As the generators supplied high-tension current for the series charging the steam plant was idle just when it was most needed on the peak load, and this led to the development of direct-current transformers, the low-tension side of which was run in parallel with the batteries.

It is interesting to note that Mr. E. J. Houghton of

* Berman Taylor-Kine.

the London, Brighton and South Coast Railway used E.P.S. cells for lighting the Pullman Limited Express in 1882. Sir David Salomons (who is still with us) and others used them for private plants in 1883. I think the records credit Mr. W. H. Preece (later Sir William Preece) in starting with the Elwell–Parker–Planté type in 1884 and changing to the E.P.S. system 2 years later. Among the notable incidents of those early days were Reckenzaun's tram-car experiments in 1883 when 1½ to 2 tons of batteries drove the car through worm gearing.

Electric launches were developed at Millwall to act as tenders and also as regulator and storage batteries for the lights on steam yachts, such as the Duke of Bedford's "Northumbria." This business later passed to friends more conveniently situated higher up the river. The electric launch "Volta" crossed the Channel in 1886 and in the same year the public trials of the submarine "Porpoise" took place. Both vessels were equipped with E.P.S. cells.

The five years that I spent on the Millwall works brought very interesting visitors, among others being Dolivo. Dobrowolski (who subsequently invented the three-phase system) and an assistant spent some time learning our methods on behalf of the Tudor Co. in Germany, or the interests which were subsequently those of the Tudor Co.

Space occupied was always a trouble and too much was sacrificed on that account. Any improvement had to be such that the same number of plates incorporating it could be squeezed into the old box, in spite of the fact that ⅜ inch separators cut by hand out of ebonite sheet had been found excellent in the L type of cell.

The introduction of the shelf, or horizontally grooved, positive plate was a Faure production. Pencils or straws of paste fell out, and this led to such improvements in the casting of the grids that there was little room in the fine serrations for paste, and the plate became essentially a Planté plate of enormous area or active surface. One method of hastening and deepening the corrosion or formation of the Planté surface was by reversing the poles of the cell. Epstein attacked the plate with nitric acid. He alone was successful in eliminating the acid when finished with, but, while the surfaces were so far good, the grooves were so coarse in pitch that they were feeble as compared with the very fine grooves now employed.

As regards negative plates the trouble was in the shrinkage of the pellets of spongy lead and consequent decreased contact with the grid. Various types of grid inwardly forked, or spiked interlaced and box types were tried to prevent the pellets falling away. Modern types include the discarded box grid combined with an expanding pellet.

Felt was used by Faure as a separator. Biscuit and corrugated mattings of various types were used at one end by the E.P.S. Co. and ⅜ in. acid spaces at the other, with Schoops "solid" electrolyte between these extremes. Now we find ample space for the modern construction of the plates where plenty of battery room is available, and suitable matting or treated wood where space is an important consideration.

As regards lugs, the change from bolting up with brass studs and nuts or even "non-corrosive" studs (which allowed plenty of scope for corrosion and heating in the joints) to the extremely heavy solidly burned autogenous channel connections is very marked.

While so-called central station plates used to stand on ¾ in. or ⅞ in. triangular bottom blocks, they are now hung from the top of the box with 6 or 8 inches clear space below them.

For central station work the development of booster systems, with one of which the name of Mr. Highfield, the President, is connected, enabled troublesome end-cells to be done away with. I have mentioned the large chills which were obsolete in 1886 at Millwall; their place is now taken by plates up to 46 inches deep × 16 inches wide, weighing about 90 lb. each, such being quite as large as can be safely handled.

Probably the first battery of large size to be installed in this country was the Tudor battery installed at Short's-gardens substation, Charing Cross, in 1899. This battery was capable of giving 1 000 amperes continuously for 4 hours and in the following years further batteries of the same size were installed in all the substations of the company. All these batteries are still in use, and although they have since been re-plated the original lead-lined wood boxes and other portions of the equipment are still in excellent condition.

The plates of the original Short's-gardens battery were built up in 2 portions, one suspended beneath the other by means of special hangers, as plates larger than 12 in. × 14 in. were not then made, and it was necessary in the case of a battery of such large capacity to have deep plates in order to economize floor space.

In the early days it was thought sufficient to put the battery away in any odd corner, usually in a dark, damp cellar, the cells being placed on 2-, 3- or even 4-tier stands, with insufficient room for proper inspection. Consequently, the supervision was difficult and the cells were grossly neglected. Battery rooms have now undergone a gradual change and the present-day room is light, airy and of sufficient area to admit of the cells being erected on single-tier stands with ample gangway space for inspection and working.

Central station cells are now obtainable which will discharge up to a rate of 300 amperes per positive plate for 20 minutes with an alternative rating of one-half the 20-minute rate for 1 hour, and one-quarter the 20-minute rate for 3 hours. I have known cases where batteries of 150 Exide cells with 85 positive plates per cell have sustained these figures.

In the application of storage batteries to boats enormous strides have been made from the small cells which were stowed away under the seats of launches to the huge batteries of over 300 cells weighing over 200 tons, which are necessary on modern submarines.

Battery makers took themselves very seriously on the subject of traction, and wrote bringing out the advantages of storage battery cars as compared with the trolley-wire system. It is a long time now since the Barking-road or Birmingham cars were run at a cost for battery maintenance of 2d. per car-mile. Efforts are now directed into the more fruitful field of vehicle traction and other special purposes, such as mining locomotives, which in some cases are used not

only as locomotives but as storage for supplies to rock drills and portable machines.

The electric brougham is not so common now as the electric delivery van. Perhaps the outstanding feature in the electric vehicle is that it is limited by the mileage run, and not by the length of the day worked. An internal combustion engine is a nuisance on a house-to-house delivery or collecting van as the engine must be kept running all the time the van is standing, or a heavy starting battery must be carried to relieve the driver of the trouble in cranking his engine. Storage-battery cars have been run on long-distance trips for exhibition purposes, but work entailing such journeys had better be left to petrol and similar fuels.

Closely allied to batteries for traction work are the ignition and starting batteries, the demands for which are so enormous. One American maker is said to have a turn-over of £3 000 000 per annum in this line alone.

The new uses and fields of work are continually developing new requirements. In old days a battery had to be reasonably free from acid creepage and could have a free gas-vent. A modern cell for aeroplane work has to be fitted with a device which will prevent the acid from escaping if it is inverted, and must also provide a high discharge rate whilst keeping the weight down to the minimum.

A new line which was not represented in the early days is the iron-alkali cell. We heard of it long before it appeared but, with the patient perseverance which his friends associate with the name of Edison, he has overcome obstacles and his battery now is a formidable competitor where light weight is a consideration.

Following the alkaline zinc–copper Waddell–Entz cell, Edison and others turned to other metals. Cadmium–copper in potassium hydrate gave way to iron–nickel–oxide, but before an arrangement and construction was developed which met the requirements of the trade much investigation had to be carried out.

The positive plates are now built up of small perforated steel tubes which act as containers and conductors for the active material which consists of nickel hydrate; this is such a poor conductor that it has to be filled in with alternate layers of finely flaked metallic nickel. The negative is finely divided iron oxide loaded into rectangular, thin nickel-steel finely perforated strip pockets. The pockets are assembled in a light steel frame or case and subjected to a heavy pressure which closes and corrugates the surfaces, making them stronger to withstand shock and improving the conductivity. The electrolyte is a solution of caustic potash. The container box is a specially treated steel case, in place of the usual ebonite. The use of these cells is somewhat restricted by their peculiar curves and characteristics which, while no bar for traction work, unfit them for central station use.

The trouble of the long first charge required has been aggravated by scarcity of and difficulties with labour. The D.P. Company have met the need by developing cells for which the first charge is reduced from about 40 hours to 15, which period need not be continuous. An 8-hour charge followed by a night's rest and another 8 hours' day charge is all the cells call for, and this meets the demands of the up-to-date workman. In the case of small, private plants the cost of the first charge was as much as the cost of the battery, but the "short-first-charge" battery puts the two in proper proportion by cutting out the expensive night work.

The life of batteries has been prolonged by improvements in design but has also been influenced by greater care in the selection of materials. The old standard of "commercially pure" no longer holds good. Lead which might make excellent paint or joints has to be tried by another standard if required for battery work. The purchase of this experience was costly and affords another instance of the inability of directors to appreciate the value of scientific work. Battery work is no longer "plumbing" but affords plenty of scope for the electro-metallurgical chemist, in addition to calling for engineering training and experience.

Sir Alexander Kennedy has stated that he was recruited from the class of marine engineers; I was serving my apprenticeship as an agricultural and general engineer when I was sent in 1881 to take charge of an engine at the Paris Electrical Exhibition. Messrs. Robey & Co. had 7 engines driving arc lighters on the Anglo-American Brush Co.'s stand. Mr. J. M. Gorham was in charge for Robey's. On the Brush side of the countershaft I met Mr. Charles Brush, Lane Fox (whose lamps they were showing), Percy Sellon and Erskine the late secretary of Mr. Crompton's Kensington Co. I met there, too, that versatile genius Hiram Maxim. On returning to the works, I was engaged on the Richardson–Neville electric governor. In 1883 I went to Spain and ran some of the first instalments in Barcelona, Valencia, Madrid and Cordova.

A recollection of the way in which Gramme machines were then made comes back to me. At Barcelona, a difference of opinion I had with the electrician as to the steadiness of my steam pressure and speed was settled by the armature firing on the shaft, to which it was fixed by a couple of set-screws with a 20-h.p. (nominal) engine to drive it!

I put up and ran the installation at the Folkestone Exhibition for the E.P.S. Co. and left it to follow Mr. Gorham as works manager. A special tester sent down to test my circuits (I had never done any before), in advance of an inspection by Mr. Musgrave Heaphy, reported to Mr. Drake that "all but two were infinity and they were more"!

After 8 years with the E.P.S. Co. I went to power station work. It is interesting to note how times have changed. My old company supplied St. Martin's-in-the-Fields against the competition of two alternating-current companies. When we wanted to extend, the only way to get our Order was by bringing direct-current competition into alternating-current areas.

Sir Thomas Callender's reference to the rushed work in Lambeth is not quite correct. The Electricity Supply Company obtained a Provisional Order for supply in the Strand area and, as the old "Gatti" works in Maiden-lane were inadequate, other arrangements had to be made. A site was taken outside the area in Commercial-road, Lambeth, and arrangements were made with the local authority to open the streets, and with the South-Eastern Railway Co. for a way-

leave for cables over Hungerford-bridge. We relied on our existing Order as giving us the right to lay mains outside our area for the purposes of the Order and, further, as not compelling us to give notices of intended works outside our area to those who were incidentally our competitors! An order was placed with Messrs. Callender to lay the mains and, as Sir Thomas describes, stores were prepared at our new site in Commercial-road ready for men who had been selected from Messrs. Callender's various contracts, who started at 12 o'clock on a Saturday preceding August Bank Holiday. The work was carried on continuously and was practically finished before our competitors had recovered from their holiday and astonishment at the march which had been stolen on them! Our attitude, which was due to the insight of my old colleague, the secretary of the Company, E. Wilmot Seale, was upheld as correct, and no Order was ever sought or was ever necessary to cover the work.

I was, in 1899, responsible for engineering the first three-phase 10 000-volt system in this country, the plant for which we had to buy abroad as it was unobtainable at home.

Our old competitors are all now supplying direct current. Lord Kelvin, the great protagonist of direct current, was called by the Metropolitan Co. to oppose our Strand Order, and he found his previous statements difficult to reconcile with his evidence against the Bill.

THURSDAY, 23 FEBRUARY, 1922, AT 8 P.M.

(Held in the Institution Lecture Theatre.)

Mr. A. A. C. Swinton, F.R.S., Vice-President, in the chair.

The Chairman read the following message which had been received from the **President (Mr. J. S. Highfield)**:—

"It has been a great disappointment to me that I could not preside over the Commemoration Meetings and I had hoped at least to attend the last meeting to-day, but unfortunately this is impossible, so I write these few lines. First, I want to thank the various Vice-Presidents and my many kind colleagues for the special efforts necessary to take over my work. The success of the Meetings is sure proof of their hearty work. The Commemoration Meetings were devised to serve manifold ends. Just as there is only one really true and just reason for drinking wine, and that is because you like it; so the first object of these meetings was to give pleasure, pleasure in meeting old friends and hearing them recall past days with their failures, trials and, at length, successes; in short, the noble pleasure of hero worship; again, to realize the supreme pleasure of visualizing the still-growing enterprise that has emerged from 50 years of team-work, carried out often by men who did not at the time realize they were working to a common end, in fact, who were often opposing one another with every arm, in the end finding that in their several ways they were really the builders of one great edifice. The second object of these Meetings, and one which I am sure they will admirably serve, was to produce a living history of electrical engineering in all its applications, and to preserve this history by producing a special number of the *Journal* containing the contributions, spoken and written, of all who have so willingly given their aid to make these Meetings so full of interest. The history of electrical engineering begins with Volta's discovery of the primary battery and with Oersted's moving compass needle, Faraday's discoveries providing means to convert mechanical into electrical energy and to transform its values, with many sidelights on the nature of electricity. As development of these primary discoveries proceeded, the measurement and definition of quantities and constants became necessary, and from the work of Kelvin, Maxwell, Rayleigh, Joule, Carey Foster, Wheatstone, Bright, Latimer Clark and many others about the years 1850 to 1870 arose not only the system of electrical units now in international use, but also knowledge leading to the better understanding of heat and its applications. It is interesting to trace the many instances where a notable advance in one science leads to advances in unexpected directions. In 1775, Watt's steam engine patent was renewed and in the same year Arkwright patented his invention of the cotton-spinning mill; the steam engine made possible the large mill, which in turn led to the development of the steam engine. Similarly, the development of the electric generator produced the high-speed steam engine, and later the original and vastly laborious work of Parsons in building the steam turbine led to the so-called super-power station of to-day, the alternator and turbine developing side by side, the one depending on the other. There would be no use for the large land turbine apart from electricity supply.

"We were truly fortunate in that Professor Fleming threw himself so very heartily into the spirit of the Council's Commemoration scheme; we owe him a great debt, as he has given us a living representation of Faraday and his work. The history of electrical engineering during the last 50 years is in fact the history of our Institution, and is recorded in the pages of our *Journal*. It starts with the trifling apparatus used with delicate skill and keen thought amounting almost to intuition. The steadily growing force of a new fact, the growing army of keen men pursuing the new idea ever broadening its applications and bringing in their train armies of skilled assistants and craftsmen, have during 50 years built up the latest enterprise of to-day. We speak of foundations, but the foundations laid by a master mind are not as of concrete, rigid and unmoving, rather their strength and security depend on kinetic energy; they hold the principle of life itself, the

principle of growth. That is the precious heritage we must preserve, and this can be done only in an atmosphere where freedom of growth is possible. Legislation in the past has hampered freedom, and I hope that the record of these Meetings may serve to spread a wider knowledge of the history of electrical engineering so that its future legislation may be guided by wiser hands."

The Chairman : The Council wish to tender their best thanks to Messrs. A. H. Allen, F. H. Masters, E. Slater and A. G. Whyte for the onerous and invaluable work done by them in condensing for Press purposes the remarks of the various contributors. The Council also desire especially to thank the editors of the daily Press for the large amount of space given by them in their columns to the accounts of the proceedings.

[The following addresses were then delivered.]

MR. J. E. KINGSBURY.

Telephony.

It is something of a coincidence that the year we are celebrating (1872) was also the year when Bell commenced his systematic experiments to put into material form the ideas on electric telephony which had been previously occupying his mind, and, as we know, those experiments culminated in his patents of 1876 and 1877. My first experience of telephonic speech was in 1878 and then through the carbon transmitter which Edison had developed after Bell's discovery of the essential principles had become known. This transmitter gave much more powerful results than the earlier magneto form. To those who have grown up with the telephone as an instrument of daily use I cannot hope to convey an idea of what it was like to talk through the telephone for the first time when it was practically unknown. The line was between No. 6, Lombard-street, and the corner of Princes-street. I was at the latter. Scepticism, which was, perhaps, a very natural first impression, had to give way to the absolute knowledge that I had left at Lombard-street the owner of the voice so clearly recognizable. There was no getting away from the fact that the instruments at either end with the wire between had provided the means for that clear conversation between my colleague and myself. The feeling of awe which came over me I have a vivid recollection of now. I marvelled then and I have marvelled more since that anyone should doubt the value of such an instrument or place any limit on its development.

Public demonstrations were always interesting and sometimes exciting. Since that time I have had a good deal of sympathy for those responsible for experimental demonstrations of new apparatus under more or less improvised conditions. At the first demonstration of the Edison loud-speaking receiver at the Royal Society soirée it broke down completely, and I remember the admiration I felt for the coolness of Edison's nephew (who was in charge) whilst taking the instrument to pieces and putting it together again when all the time an excited crowd of scientists and their friends were waiting at the door for admission. But it was a brilliant success nevertheless. The public début of the Edison transmitter was made at a lecture by Professor (now Sir William) Barrett at the London Institution on 30th December, 1878, in the arrangements for which I was concerned. I remember that in the subsequent questions or comments at this lecture the rivalry of Bell and Edison interests was clearly apparent. Sir William Barrett also participated in the first long-distance trial of the Edison transmitter. This was over the Colman's line from London to Norwich, 115 miles, in November, 1878. The line was single, of course, and of iron, and the induction very considerable. My recollection is of a constant cackle through which the spoken words emerged as through a screen.

Another early public demonstration was Conrad Cooke's lecture at the Society of Arts with Tyndall in the chair.

The loud-speaking receiver was an admirable and very popular instrument for demonstration purposes, but after using it as an exchange instrument one could appreciate the great superiority of the magneto form. During conversation it was necessary to turn a crank revolving a moistened chalk cylinder. My firm's office was one of ten (*The Times* office was another) connected to an experimental exchange—the small beginning which was to become the main purpose of the telephone.

Although the Bell Company in London had at an earlier stage started business in the supply of telephones for what are called private line purposes, it was really as exchange organizations that both the Bell and the Edison Companies seriously commenced business. It was in 1879 that this start was made and the adventurers launched out upon a new enterprise, using such experience as was available and adapting their methods as new conditions were met with.

In order that you may visualize the conditions as fully as possible, you will bear in mind that the telegraph lines which existed were for the service of the public collectively. The lines were consequently few. Telephone exchange service required a line to each individual user. The lines were therefore many, and in the neighbourhood of the exchange itself became congested. Again, telegraph lines were mostly along roads or railways. The telephone required that they should be in crowded areas, and the only available method was to carry them on house tops. So telephone engineers had to develop new methods for carrying increasing numbers of wires on routes to centralized points. Add to this fact that the telephone pioneers in England had no statutory powers but were dependent on the permission of private owners for the placing of their fixtures, and you may form some conception of what the line difficulties were. But it was an extensive development of pre-existing conditions. Not so the switching system. The principle of diverting telegraphic lines by means of switching was old, but

never before had one member of the public been able on request to be put into communication directly with another member of the public. Any momentary break in the continuity of the circuit must interrupt conversation, and the continuity of the circuit depended upon the proper working of numerous springs and movable contacts. You may imagine the trying time of the pioneer in remedying defects whilst at the same time carrying out a new service with most sensitive and intricate apparatus.

The development of exchange apparatus has been too great and too complex to permit me even to attempt to enter upon details, but, having regard to numbers alone, the early switchboards of ten lines had soon grown so that by means of what was known as the multiple switchboard ten thousand lines could be handled in one central office.

The fact that the public themselves were participants in the carrying out of the service introduced a new factor which had to be taken care of. This necessitated the introduction of methods of management and control as well as the adaptation of appliances, and only by careful study and steady application were satisfactory methods of exchange management developed.

Having built up systems of considerable extent on the single-wire system, telephone organizations were forced to take in hand the question of building them all over again on the double-wire system. This was rendered the more urgent by the development of other electrical services, such as tramways. Overhead work was already crowded enough with single wires. What would it be if they were doubled? Bear in mind that underground methods hitherto in use which worked quite well for telegraphs were found to be detrimental to telephones. The distances over which speech could satisfactorily be transmitted were much shorter underground than overhead, so new departures had to be made. Lead-covered cables were then introduced: first filled with insulating material such as paraffin wax and then vastly improved by omitting the insulating material and relying only on air and the paper coverings of the individual wires. By these aids the burying of the conductors became possible within town areas, but open wires were still required between towns. Then followed at a considerable interval the practical application of the loading principle. By the insertion of suitable inductance coils at suitable intervals in the cable circuits, the talking distance increased to the extent of permitting the use of cables upon congested rural lines to a hundred miles or more. The further extension effected by the application of that beautiful invention the thermionic valve amplifier has quite recently been fully related before you. Metallic circuits in town areas were first introduced for long-distance (or trunk) subscribers, but it was early realized that they must become general, and eventually they were. The plan adopted was to draw cables into conduits, but in London and other places it was necessary to reconstruct the system overhead in consequence of the refusal of local authorities to permit the use of the streets.

With the doubling of the line circuits necessarily followed the construction of metallic circuit switchboards. New problems arose but experience already gained was considerable, and of numerous designs the most satisfactory was selected and put into operation. The metallic circuiting called for a modification in the subscribers' instrument but not an entire change. The call was still made by turning the handle of a magneto. Yet another reconstruction of exchanges and replacement of subscribers' instruments followed the introduction of the central battery system, which is familiar to you all from daily use. Whilst generally regarded as comparatively new, automatic systems which are now claiming more attention are almost coincident with manual systems, and have developed from very early beginnings.

One urgent requirement in the introduction of new systems must be borne in mind. It is less difficult to create something new in itself than to adapt the new to work in with the old. Thus in all telephonic advances a prime requisite is that the new must be adapted to work with the previously existing system. Otherwise there would have to be an immediate duplication or a cessation of service—an impossible situation of course.

To summarize very briefly what has been achieved in the period of our review I will take just two aspects—numbers and distance. I may remind you that in 1878 the telephone was first used in exchange service. To-day there are about twenty-one million telephones connected to various exchanges throughout the world. In their first business circular issued in 1877 Bell and his associates stated that they were "prepared to furnish telephones for the transmission of articulate speech through instruments not more than twenty miles apart." To-day conversation has been accomplished over five thousand miles. The continent of America from East to West was conversationally spanned more than seven years ago. Given commercial conditions to justify the cost the American Continent from North to South might equally be spanned. No further invention is necessary for the accomplishment of that result. It follows that an Indo-European telephone is scientifically possible, though I am far from wishing you to assume that it is commercially probable. Yet as a link in the chain under suitable international arrangements conversation between London and Constantinople is by no means an idle dream.

In the consideration of the subjects which are being brought before you, the Council have not limited us to the technical features but have asked that the effects of legislation may also be considered.

Now there has been a good deal of legislation in regard to telephony and most of it is no longer operative, but the dominant factor is the Act of 1869. This was passed by Parliament in anticipation of the purchase of the telegraphs by the State and was interpreted by the Courts as covering the means of communication by telephone. The decision has often been criticized but I am not one of the critics. I see no reason to doubt the accuracy of the interpretation which the Courts gave. As Sir Frederick Bramwell said: "The draughtsman who drew that Act did his work so well, in the interests of his employers, that the uninvented telephone was subsequently found to be embraced within the wide language of the Telegraph Act." As a result of judicial

decision then the telephone was a monopoly of the Government. The State was actively engaged in conducting a telegraphic business when the telephone was invented. The State had not created the telegraphic business but had acquired it ready made There was still prevalent the idea that the State was not well adapted to promote a new type of enterprise but was adapted to carry on one already developed. So for the telephone the method of licensing was adopted and the Telephone Company became a licensee of the State.

Whether Napoleon ever said that we were a nation of shopkeepers has been doubted, but it is certain that Dr. Johnson said that " a merchant seldom thinks of any but his own trade." In a nation of shopkeepers an individual shopkeeper may take limited views but if he fails to meet the requirements of his customers he goes out of business and some other takes his place. The nation is the gainer from the increased efficiency which results. The nation is disinterested and can hold the balance fairly between the individual shopkeepers. When the nation itself is the shopkeeper the position is very materially altered. It is not disinterested or impartial. That was the position of affairs here when the telephone was introduced. The nation was a shopkeeper having recently purchased a business for several millions of pounds. Improvements in means of communication have been recognized from time immemorial as being of advantage to the State, and had the nation not been a shopkeeper this might have been thought of, but the nation was a shopkeeper and approached the subject from the shopkeeper's narrow view of conserving its immediate interests as a vendor of telegraphic service.

The licence provided for the payment of a substantial royalty in consideration of the permission to do business, but other conditions were attached. A central point was decided upon in the several areas and the licensee permitted to give communication within a specified radius—generally about four or five miles. Why? Because the telegraph revenue in local areas was small but became more important as the distance increased. Any communication between the specified areas was to be subject to special provisions and special royalties.

To criticize in the light of after events is easy enough. The conditions were introduced of course by the custodians of the nation's shop, whose duty it was to protect the nation's investment and do their best to prevent any impairment of the shop's turnover. The matter for regret is that there was no one—at any rate of sufficient authority—to take a broader view. It would have been worth while to give a thought to the larger question of what the nation might gain by improved communication by telephone as a set-off against a possibly reduced revenue from telegraphs.

It is impossible within the space allowed me to review the whole of the legislation applicable to the telephone or the Government's varying policies regarding it. As it began so it continued. Only once did the Government take a broad view, and that was when Mr. Fawcett, as a result of public protest, abolished the four-mile radius and allowed the Companies to connect up where they liked. The more or less compulsory purchase of the trunk lines of the Company introduced a recognized defect in having two authorities manipulating a single call and was promoted as a set-off to the decreasing traffic from long-distance telegrams.

From the beginning great stress was laid on the importance of competition, which was perhaps excusable in the early stages, but as time went on it became clear that competition in telephony was wasteful in any case and not of advantage to the public. This state of knowledge had been reached when, as a result of Mr. Hanbury's actions, the municipalities were encouraged to undertake a competition which private enterprise had abandoned. In view of the then state of knowledge, it is difficult to see any purpose in such a policy other than an effort to depreciate values against subsequent purchase, oblivious of the fact that any possible saving on one system must be small compared with the subsequent cost of combining two.

The question whether our telephonic development accords with our commercial importance and social standards usually gives rise to arguments regarding differing circumstances and national characteristics. It may then be worth while to consider it on general lines. New services grow with their growth and spread from their start as an expanding circle, the rate of expansion being proportional to the spread of the general knowledge of their utility. An example in our own locality not fifty, but nearer a hundred and fifty, years old may be cited: " On the 25th April, 1785, the first meeting of the founders of the Lambeth Water Works was held, when a list of 629 houses to be immediately supplied was submitted, as well as a second list of 637 houses with regard to which which it is recorded on the minutes that the occupiers 'might be induced hereafter to apply for water and to make a compensation for the expense of driving pipes for the supply of their houses when they shall perceive the comfort and conveniency of water by the experience of their neighbours.'" It is the experience of their neighbours which prompts other individuals to adopt a new service, and if that service is restricted in its start the original circle is small, whilst the continued absence of freedom contributes further to the result that its rate of expansion must be slow. If we reach that conclusion on general principles we may not unreasonably call evidence of comparative statistics in support. These show that of the twenty-one million exchange telephones in the world at December 31, 1920, thirteen and a half millions were in the United States and barely one million in the United Kingdom. Again, the number of telephones in the Dominion of Canada with its eight million inhabitants was only 13 per cent less than those in the Mother Country with forty-seven millions of inhabitants.

It is useless decrying legislation. After all, legislation is not spontaneous. It represents more or less the public opinion of the moment, and during the greater part of the period of our review it must be recognized that as a rule public opinion has seldom given thought to the utility of public utilities. It would readily suffer indirect loss in pounds rather than permit private enterprise to make the decimal of a penny profit. In later

and equally critical stages the telephonic development has been checked by the refusal of local authorities to allow underground cables.

The city of Glasgow set up the principle " that no Company should obtain possession of the sacred soil of the streets of Glasgow," even if the Company was carrying on the Government's work under licence. London, both City and County, refused permission for underground pipes except upon conditions for telephone rates which were impossible of fulfilment. The Chairman of the Highways Committee of the County Council stated in 1901 that for eight years they had been defending the streets of London against the Telephone Company with a view to obtain a tariff comparable to that in the provinces. Meantime the telephone users of London were subject to all the interruptions incidental to overhead lines. Early in 1900 an exceptional snow-storm partially dislocated the Service. That London was not comparable with the provinces in the cost of telephone service was well known, and it was impossible for the Company to comply with the conditions. So London was eight years behind in the application of the recognized method of construction for continuity of service and convenient expansion.

And all these bars to progress were instituted with the firm but misguided conviction that the interests of the ratepayers were being conserved. The loss which the same ratepayers and their successors were incurring by lack of prompt and economical communication was not thought of.

So far as telephony is concerned, the period of divided interests and Local Government embargoes is over. The telephone is no longer a stepchild in an unsympathetic home but has been adopted with full rights and is cherished equally with—perhaps even more than—the elder telegraph sister. The keenness felt by the technical staff—from the Chief downwards—for telephone progress and development is within our knowledge and is on record in our *Journal*. That there is some leeway to make up is probably recognized by the Department concerned, and it behoves us to promote their efforts so far as many be in our power. Public appreciation of telephones is still uninformed. The subscriber still thinks of the cost of the instrument he sees and is oblivious of the vast investment behind it. It is distressing to note the constant criticism of rates based on profound ignorance of the facts. We should do our best to support the sound principle that the service must be paid for by the users in the aggregate and as nearly as may be possible in proportion to use. I am not committing myself to all the details of the charges in force but to the broad principle. Because a Government is running a service is no reason why it should be supplied below cost. It is worth to the user all it costs and more. Broader views are needed all round and not the least among the critical subscribers. The general public attitude to public service enterprises is perhaps undergoing a change. But that change may well be accelerated. If has been in the main purely selfish. It has not given a thought to facilities obtained but has always grudged a profit made. It would be refreshing to hear occasionally some word of thanks for, some evidence of appreciation of, facilities which in most cases private enterprise has initiated against great risks and sometimes much contumely. By experience the public may be got to realize that they cannot have it both ways. But, while experience strong enough to produce an impression is being obtained, progress is unhappily being seriously retarded.

In referring to legislation I am of course limiting my remarks to our own country. On the technical side I have recognized that science has no boundaries. The record is one of which electrical engineers may well be proud. In no branch of our industry has more thorough and systematic effort been made to utilize the discoveries of science and apply them by inventive ingenuity to the use and convenience of the public than in the case of telephony. In the discoveries of science we here may claim and will certainly be allowed an honoured place. In many of the applications we cannot overlook the predominant share of the United States. The problems of telephonic communication are, in the main, the same the world over. The constant growth and development in the United States brought these problems to the front earlier than elsewhere, and the systematic efforts to solve them were in most cases fruitful of results before the same problems arose in other countries. That they were always free from disturbing difficulties there it would be a mistake to assume, but in the main telephone organizations of the United States have had freedom to carry out a wise policy of development early formulated by the pioneers and steadily maintained since. The conditions here have been exactly the reverse, with consequences to national economy and efficiency which are serious. A bold policy is now needed and there is no time to lose.

MR. G. W. PARTRIDGE.

Early Experiences in the Electric Supply Industry.

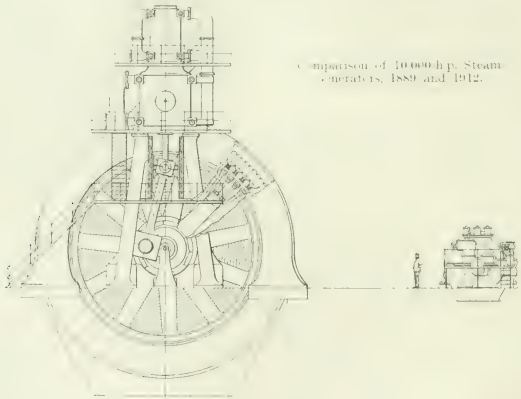
As by far the most important work in my career was carried out while in the employ of my present Company, I think it will be more interesting to the audience if I give some idea of the difficulties we had to contend with and the work carried out between 1887 and 1892 than to refer to my still earlier experiences with the Anglo-American Brush Company between 1884 and 1887.

With the Brush Company the series arc-lighting system was in use and groups of incandescent lamps were run in series with the arc lamps on circuits working up to pressures of 3 000 volts. Why more people were not killed in those days can only be accounted for, I believe, by the general fear and awe exhibited by the public towards electricity in all its branches.

Dr. Ferranti, under whom I had the privilege of serving, has told you his experiences in the very early days, so I will endeavour to recount a few experiences when my Company commenced operations.

The late Earl of Crawford was appointed by the Government on a Commission in 1882 to visit the Paris Exhibition. When he returned to London he and Sir Coutts Lindsay decided to install a portable electric light plant in a yard behind the Grosvenor Gallery, and this plant was erected in 1883. From this small beginning emanated the Sir Coutts Lindsay Company. The system adopted was the series a.c. system of Gaulard & Gibbs; the current being supplied by Siemens machines to a overhead system of mains at varying pressures depending on the load. A sample of a Gaulard & Gibbs transformer can be seen in the Institution this evening. Owing to the induction caused by these mains to the telephones in the neighbourhood it was decided to alter the system so that the lead and return circuits were run side by side, which, to a certain extent, got over the trouble.

Dr. Ferranti, when he became chief engineer, seeing



Comparison of 10 000-h.p. Steam Generators, 1889 and 1912.

the difficulties of this series system, decided to adopt what was then known as the "parallel" system of transformers, and had the whole equipment changed over to the parallel a.c. system, which was eventually to revolutionize the whole electric generating and transmitting system of the world. The generating plant of course had to be reconstructed and two 750-h.p. generators were installed, which ran at 250 r.p.m., driven by ropes and working at a pressure of 2 500 volts between conductors, which at that time were both insulated. These two generators were, I believe, at that time the largest in the world. A view of these is shown (Plate XII). The two generators were not run in parallel, the circuits being switched from one to the other as the load varied. This plant worked very satisfactorily and gave a supply for the whole neighbourhood (see Plate XIV) from an overhead system of mains.

This area extended from the Royal College of Surgeons in the east to Albert-gate in the west, to Regent's-park in the north and to Charing Cross railway station in the south, and all north of Oxford-street, taken over at a later date by the Metropolitan Company when they acquired the Marylebone area. Rubber-covered cables of excellent quality made by the Silvertown Company of three sizes, namely, 19/15, 17/16 and 7/20 B.W.G., were employed. These were carried by means of rawhide tags and rings from galvanized steel suspender cables. Originally both cable and suspender were insulated by means of special bell insulators. A slide shows the terminal pole of the overhead 2 400-volt system on the roof of the Grosvenor Gallery in 1887. But later on the bell insulators insulating the rubber cables were removed and replaced by oil insulators. These were a large type of pin insulator, the petticoat of which was turned up internally and filled with a thick oil. There were five circuits, namely, Piccadilly, St. James's-street, Oxford-street, Regent-street and Park-lane. Each circuit had its particular day for being taken off for jointing new consumers, and we never had any trouble with the overhead system the whole time it was in use. The service cables, on leaving the poles, were taken down through the walls in porcelain tubes cemented in chases cut in the walls and run to a specially designed fuse and switch. I have here a sample of the original porcelain fuse for 2 400 volts, and a double-pole switch for controlling transformers having a capacity of 20 kilowatts, 2 400/100 volts ratio. No cable was visible inside the house except where it entered the transformer, so that there was very little danger of it being touched accidentally. Later on a special cable (61/17) was ordered, as it was proposed to run overhead from Deptford by a special route. This cable was of excellent quality, and some of it has been in use ever since. A sample of the original is on the table.

The London Electric Supply Corporation was formed

in 1887 with a capital of £1 000 000, and the Deptford station was started soon afterwards. The whole scheme was severely criticized by all the experts of the day, including Edison, who visited the station in 1889. The alternating-current engineers, as they were then called, were looked down upon and certainly disliked by our competitors the direct-current companies; in fact at the Institution there was what was known as the "High-Tension Corner" left vacant for our use. Deptford started running early in 1890 at various pressures and under different conditions, until on 15th November, 1890, the original Grosvenor Gallery station was burnt down.

The accidents and breakdowns which occurred before we completed the concentric earthed system are too numerous to mention, but I have looked up my diaries, and give one instance of many.

"18*th June*, 1890.—Converters at Grosvenor failed and current went through at 5 a.m. Deptford running at 6 000 volts, one pole earthed. This accident caused about 5 000 volts to get on the 2 500-volt overhead system; destroyed 46 house converters and caused two fires in consumers' premises."

Further extract of actual damage at consumers' premises:—

"Current had arced to gaspipe, burning away about 2 feet, probably through base of secondary fuse which was close to same. Insulation of secondary wires in the house badly burned; bell wires also burned, tapestry covering same burned; wooden joists badly scorched and burned."

This is only one example of what happened in those days. Time does not permit me to give other instances.

The converter, as it was then called, was nearly always placed at the top of the building out of reach of the consumer and as near to the overhead system as possible. The next slide shows an original 25-light Ferranti converter having a ratio of 2 400/100 as in use in 1887.

On 3rd December, 1890, about three weeks after the Grosvenor fire, a further effort was made to run from Deptford on the old overhead system, but the temporary transformers burnt up again, so that the whole system was shut down until it could be altered to the underground concentric earthed system, which has been in use ever since.

To give another example of accidents; at one time an arc of 10 feet length was started up between the terminals of a transformer and the iron roof of the building. One of our men threw his hat at the arc and thus put it out. The next thing done was to make up what was then known as a "Flapper" for putting out arcs; this was composed of a wooden handle with two pieces of sheet fibre at the end. Such apparatus is even to-day kept in reserve for putting out arcs on the old lighting board which I designed thirty years ago at the Deptford station, for working at a pressure of 11 000 volts. During the period of shut-down (about four months) our consumers had no electric light. I remember seeing a shop with two large candles burning in the window, which bore the inscription "A Present from Deptford." Our rivals, the direct-current companies, were busy during this period taking over and connecting up our consumers, so that when we did start running again on 16th February, 1891, our load was much diminished.

The first underground 2 400-volt concentric cable was laid in the Strand in September, 1890. A fault occurred and we had great difficulty in locating it owing to the numerous branches connected to the cable. A bright idea struck me of passing an intermittent current through the cable to earth at the fault, and locating the position of the fault by means of a telephone. A special coil was made, about 4 ft. long, and this was solemnly wheeled down the Strand followed by me with a flexible cord attached and telephone receiver to my ear and about a hundred people walking behind. I remember hearing someone ask the foreman (West) what we were doing and he replied, "The Governor has lost sixpence and we're a'looking for it." Things went splendidly until we wanted the current reduced near the fault; I endeavoured to ring up the substation on the telephone to tell them to reduce the current; it was found, however, that this intermittent current had entirely taken charge of the whole of the National Telephone Company's system in the area, which in those days ran with one pole earthed, and nobody could speak on the exchanges. As our then chairman, Mr. Staats Forbes, was also chairman of the National Telephone Company, we left the fault and said nothing about this very interesting experiment, which to-day (32 years later) is known as the "leader system," used in war for guiding ships through minefields and fogs, etc. The experiment I have described certainly guided us in the right direction, but it would certainly have got me the "sack" had my chairman known who was responsible for the disturbance to his telephones. The newspapers the next day had references to "A mysterious magnetic storm" which had affected the telephones not only in London but between London and Paris. The curious thing about this fault is that it sealed itself up and has been under a continuous working pressure of 2 500 volts ever since.

This is only one of many "makeshift" inventions of those early days which have eventually proved themselves of inestimable value to the industry. Among other inventions of the early days may be cited:—

(1) Transformers first used in parallel.
(2) The use of a high-pressure concentric system with one pole earthed.
(3) Paper-insulated cable first made.
(4) A.C. generating stations first run in parallel.
(5) The E.H.P. system of generation and distribution (including that of a combined system of extra high pressure, high pressure, and low pressure).
(6) The oil switch.
(7) Ageing of transformer iron, etc.
(8) Numerous methods of control of generation and distribution of 10 000-volt system.

Work was thoroughly well done in those days, and I think I cannot do better than show a photograph (see Plate XIII) of a substation equipment at Cockspur-

street which has actually been in use ever since 1892—a period of 30 years.

I need hardly say how numerous were the breakdowns and difficulties which occurred in transmitting current at a pressure of 10 000 volts from Deptford to London and how, under Dr. Ferranti's guidance and after everything else had failed, we manufactured our own cables, which were of the concentric design and made up of an inner and outer copper tube forming the conductors, with $\frac{1}{2}$ in. of paper between them. The insulation used throughout was brown paper impregnated with ozokerite wax. Cables were made in 20-ft. lengths and about 28 miles were laid with a joint every 20 ft., so there were over 7 000 joints. In the first instance these mains were run for a considerable portion of their length on the walls and arches of the South-Eastern Railway, but finally the whole of the cables were laid underground. Samples of this cable are also shown, and at the present time there are about 14 miles still in daily use.

The directors of the London Electric Supply Corporation, under the late Lord Crawford and Lord Wantage, both of whom (particularly Lord Wantage) personally found large sums of money to perfect and carry out the work they had undertaken, backed up the brains of our engineer with their financial, personal and moral support, and but for them the whole system of generating high-pressure alternating current would have been set back for many years before coming into its own.

I am showing a sample high-tension coil of the first generator in the world to generate current at a pressure of 10 000 volts. It was no mean achievement to design, manufacture, and erect such apparatus which had a capacity of 1 500 h.p., by far the largest dynamo in the world at the time when other supply companies were generating at 100 and 200 volts. The diagram on page 432 shows a comparison of the original 10 000-h.p. generator driven by two 5 000-h.p. tandem engines, and a 10 000-h.p. turbo-generator supplied in 1912.

A photo (see Plate XIII) is also shown of the cast-iron rotor for holding the coils which, when complete, had a diameter of over 40 ft. Another interesting photo is that of one hundred 100-volt incandescent lamps lighted in series by 10 000 volts in 1887, the first time we ever saw this pressure of 10 000 volts in actual use.

As regards the difficulties we have had to contend with due to legislation, it has always been a matter of great surprise to me that electricity undertakings should be treated by Parliament differently from water, gas, railways and other public service undertakings. Yet we have always been and still are strangled by legislation. In 1882, after many difficulties, Parliament was induced to give leave to private companies to break up streets for the purpose of laying mains, but only on condition that the local authorities could purchase the companies' undertakings in 21 years. This proved so unsatisfactory that it completely held up private enterprise for a further period of six years, until in 1888 the Act was amended and the companies' tenure was increased to 42 years.

Association or actual electrical connection for supply between the companies was prohibited by law, so that it cannot be wondered at that each company started up on whatever system it thought best for its particular district, quite independently of what was being done by its neighbour. Matters were allowed to drift on from year to year, each company improving its system until 20 years later, and after many difficulties and at great cost to the present London Companies, the 1908 Act was passed which permitted these companies to assist one another and supply railways. The difficulties experienced by the companies during those 20 years, owing to Parliamentary restrictions, can never be exaggerated. To give an example, my own Company risked its capital in 1906 in order to install the necessary plant for the supply to the Brighton Railway, although it had no legal power to supply out of its area; yet something had to be done to secure this contract. During those trying years I have spoken of, hundreds of thousands of pounds were spent by the companies on electrical plant and mains which had to be scrapped wholesale, and in some cases scrapped and replaced two or three times over. The London Electric Supply Corporation alone spent no less than £350 000 on plant and machinery, some of which was never erected. It was said, and perhaps rightly, that Deptford was 20 years before its time, but to-day everyone is agreed that the only way to generate and distribute electricity over large areas on a large scale is by the a.c. system first adopted by the London Company 35 years ago.

When one considers the extraordinary pioneering work carried out and the huge sums spent by all the London supply companies, it strikes one as a great hardship that this country as a whole should not have benefited more than it has done from its early pioneering work. During this period other countries looked on, but as soon as they saw the advantages of the high-tension a.c. system of generation and distribution they were not slow to adopt it. Large supply companies sprang up all over the world; companies with enormous areas and far-reaching powers, supported in some cases by their respective Governments, whilst this country, thanks to Parliament's terror of monopoly in the hands of a company, or thanks to a then existing idea that the best public service could be obtained by municipal trading, was left to work out its own salvation with its large number of supply authorities each cooped up in its own small area with no powers to consolidate, or inducements given to unify systems to enable companies mutually to assist one another. Parliament was certainly wise in the early days in not setting up a technical committee to standardize and put into operation any one particular system of supply. Had such a committee been appointed I am convinced that the low-pressure system of d.c. generation and transmission would have been adopted by the experts of those days, probably partially governed by American practice, in which case the high-pressure system would have taken even longer than it did to come into its own.

The standardization of plant and machinery is always to be commended, but the standardization of any particular system, especially in an industry like

electricity, is always a very dangerous proposition. The method adopted by Parliament in those days as regards systems and standardization was to leave matters alone on the principle of the survival of the fittest, and I am convinced that had this country the advantages given it, as other countries have had by their respective Governments, not only the supply authorities but also manufacturers of plant and machinery would hold a place in the world's industries very different from those they hold to-day.

As to what is to be the future of electricity supply in this country; what the 1919 Act is going to do for us; what the Commissioners can do, or will ever be able to do; or where the "cheap and abundant supply of electricity" is to come from, are all about as vague as they were before the war. We have the lessons of the telephone and water companies before us, and can only hope that this unfortunate electric supply industry will not drift into such a shocking condition of public control as they have. Surely, if undertakers are prepared to come forward and find money to perfect the supply of electricity to the public, it is for the guardians of the public to make it as easy as possible for them to carry out their work so long as profits are moderate and the prices charged to the public are reasonable. As I have already stated, the London supply companies have experimented and spent huge sums on plant and machinery in perfecting their systems of electric supply, and from a technical point of view we have really evolved a very successful industry, but what we have to do now is to release ourselves from the stranglehold perpetrated by the legislative errors of 40 years ago.

I should like to take this opportunity of formally presenting the 10 000-volt coil, transformer, cable and other apparatus to the Institution if the President will accept them as a memento of this auspicious occasion.

MR. B. M. DRAKE.

It must be difficult for young electrical engineers in these days, when everything is cut and dried and there is a precedent for nearly every problem that arises, to appreciate the condition of affairs that prevailed in the early days of the industry. What knowledge existed was often retained as a secret, with the result that many, including myself, were thrust into positions of responsibility with little but common sense to guide them, and no books of any practical value to which reference could be made.

After being trained for four years as a mechanical engineer at Sir J. Whitworth's I was given charge of the fixing of the machinery in their new works at Gorton near Manchester, after which I was told to return to the drawing-office till something else turned up.

At that time, however, in 1881, glowing accounts were coming through of the openings in the new electric light for which mechanical knowledge was wanted, and my father gave me an introduction to Sir H. Tyler, another Royal Engineers officer of his own standing and Chairman of the Brush Company.

I obtained work with the Brush Co. as a fitter, in Belvedere-road, and managed to get myself handed on from one shop to another until in a few months I had a general knowledge of how the Brush dynamo was made and their arc lamp adjusted. Why more people were not killed there is a marvel, as the arc lamps with high voltage were hung just above the benches, and it was a common joke to carry a hidden wire to one's tools and watch the resulting shock. As the cables were leaky and the floors often wet, it was quite a toss up as to how much one got.

In another department, the lamp-testing room, it was rumoured that a raging toothache had been instantly cured by accidentally touching two racks of lamps; but the somersault that accompanied the cure was regarded as a drawback to this treatment.

I was next allowed to go to the Exhibition at the Crystal Palace and be initiated into the mysteries of wiping commutators and listening to the shrieks of the large arc-lamp which kept shifting its crater. After a few weeks there I was sent for and asked if I thought I could take charge of some men to work the Spanish patent in Madrid, and whether I could start immediately. Naturally I assented, as I should have done if I had been asked to light the city. We took the parts of a small machine and a lamp ready for assembling with us, and had an amusing experience with the Custom House people on the border. They made out a bill, and as I did not know their coinage I held out a handful and let them help themselves. Just as the train was starting they returned in a fury and tried to pull me out of the train. Naturally, I did not intend to leave my men, and a crowd collected to see the fun, when a Spaniard who could talk English explained to me that I was accused of smuggling. They had found that the coil of "rope," on which no duty had been charged, contained copper wire hidden inside. Explanations and a few pesetas enabled us to proceed on our journey.

On arrival at Madrid I made use of an introduction to a member of the Embassy, and he passed me on to the head of the Fomento or Patent Office.

I then hired the use of a shop with some power, and put up the name of the Brush Company, at the same time requesting an official to come and certify the manufacture in Spain. He came round after dinner, and was shown a single lamp without a globe, suspended by a rope on which dozens of flies had collected, which cast shadows like monkeys on the ceiling. When the rope was shaken the monkeys ran about, and the official clapped his hands and was prepared to certify anything. This was the first arc lamp in Madrid, and I had to show it to many people and to put up more strings for the flies to cast their shadows.

I was next instructed to erect a demonstration plant at the Buen Retiro public gardens, as the engineer who was to have done this work was not forthcoming. The fixing of the semi-portable engine and boiler and the dynamo presented no difficulties, and I hoped my men knew something about the electrical part, as my

short experience of a few weeks at the Crystal Palace did not carry me far. I found, however, that they knew less than I did, and as we had to improvise many omissions, including a shortage of cable, and there was no wire to be bought in Madrid, it was an anxious moment when we started up and wondered whether anything would happen.

A part of the circuit consisted of iron hurdles suspended from the trees, which was regarded as part of the Brush system and puzzled the Germans who were struggling to get an installation, on which they were engaged, started before ours. However, by working right through the hot period of the day when everyone rested, and at night, we managed to beat them although they had a good start, and to my relief the lamps lit up. The late King of Spain came to see it, and congratulated me on behalf of the British on showing the first electric lights in Madrid.

A number of incandescent lamps had been sent, but no one knew how to connect them, and at the Crystal Palace the so-called sub-division of electric light had been kept a secret. Having seen nothing but series work I connected the whole of the lamps in series, and put this series on to the terminals as a shunt to the series of arc lamps, and then cut down the number till they were at what I supposed to be the correct brilliancy. The dynamo had to give the extra current, but it worked all right, and the King and the public were quite pleased. If a filament went it usually fused up the wires attached to the lamps, for there were no lampholders; and the series circuit was maintained.

After the light had been in use for some time a Spaniard appeared on the scene who wished to take over the working, but as the Brush Company, in reply to a cable, told me not to comply till the Company was formed, I was placed in a difficult position, which ended in a quarrel.

The engine driver came to tell me that he had been ordered to get up steam on an off night for the Spaniard to show his friends what he could do. I went there with a stalwart fitter and offered to work it, but was told to go away. I then pocketed a brush and awaited events.

After several futile runs one of the party told him I had taken something off the machine and they formed a cordon round the door, which we decided to rush. We managed to get away, but were stopped by a cab, and a Spaniard explained that he was one of the party and that we were to be arrested at out hotel for theft and had better go elsewhere, which we did.

As the agent for the Brush Co. was returning by a night train I awaited his arrival, and while handing over the brush, the Spaniard, who had been hunting for me all night, put in an appearance. He said he was the legal owner and I should first go to prison for theft, and when I came out I must fight a duel with him.

After the agent had succeeded in separating us he cabled for instructions, on receipt of which I went to Lisbon with orders to put right a theatre plant which had broken down, and to collect the cost before I left—no easy task. However, we found both bare wires lying on a guttering, and a trial showed that fortunately nothing else was wrong, so we put back the short-circuit until a considerable sum had been lodged at the bank, and the manager was so pleased with his extra takings that he made me a present before we left for 10 days' tossing in a Hall's cattle-boat.

On my return I was farmed out to sub-companies who were in difficulties, and was sent to Cleethorpes near Grimsby, where a street-lighting contract had been made and no light was obtainable. There I found many miles of overhead wire in excess of what the machine could supply, so I cut off the outlying lamps, and, agreeing to pay for oil lamps for these, got the plant accepted by the local authorities.

Soon afterwards I was appointed Managing Engineer of the Brush Midland Company, and subsequently of this Company and the Great Western Brush Company, where I was made responsible for the early supply stations at Bristol and Cardiff. When taking over Bristol a late official kindly put a large quantity of salt into the feed water, which caused priming. The stokers ran away, leaving me with two semi-portable sets running and the whole place full of steam. While groping my way to the plant the belts came off, one of which hit me and tore off the gas bracket, which then caught fire. I ultimately found the dynamos still working, the current having reversed from Wills's storage battery, and the dynamo, with its commutator flaming, was driving the countershaft.

Bristol was lighted with arc lamps in the street, and the series circuit was diverted into any shop or house *en route* where a group of incandescent, lamps taking 10 amperes, was fixed. A cut-out with a shunt and series coil was designed to cut out the group if too many filaments failed; but as the button contact generally burned out after a short time, it was usual to keep a cab in attendance to get to the resulting fires.

I went for a holiday to America and came back with an offer for the sole agency for the British Thomson-Houston system in Great Britain; but the companies would not look at it. Shortly afterwards, however, they were absorbed by the parent company, and I was offered the position of Managing Engineer of the Electrical Power Storage Company in 1884. I found that nearly all the batteries which were sent out failed in the course of a few months, and no one knew why. I therefore persuaded the Board to stop manufacture until investigation could be made, and as the Company was losing about £15 000 a year I did not think matters could be much worse. There were many theories amongst the men as to the cause of the disease, and I started investigating a number of the most plausible of these in order to show me that under this or that condition the trouble did or did not occur.

No one could produce it, but one man got ill and his plates began to swell and crack.

This led me to the conclusion that it might be a matter of charging, as all the others had been charging regularly and his were left empty. I therefore had the discarded cells charged, and, finding this improved matters, I sent to all users and asked them to alter the working instructions previously sent, that they must never more than partly charge, and told them to try overcharging for a time. I was in this way

able to save many thousands of pounds' worth of cells, but some had gone too far to recover.

In 1886 I read a paper before the British Association on the necessity of forming and maintaining an electrolytic protecting coat of dense peroxide on the positive plate, which arrested local action between the lead grid and the active material, and made lead storage batteries feasible.

It is interesting to note that most of the later improvements in batteries were tried in the early days; for instance, a number of cells were sent out with wood separators, but as the wood was not converted to cellulose, acetic acid formed, and this type of separator was abandoned.

The combined separator for vehicle batteries, consisting of treated wood faced with spun glass in a particular form which can be held against the positive plates to retain the active material without being destroyed by nascent oxygen, was narrowly missed by others, who used glass wool and woven glass, and in one case even glass wool and wood, but did not hit upon the successful solution of the problem.

The traction cell designed by Mr. Reckenzaun for the E.P.S. Company gave as much per pound as anything since put on the market, i.e. about 10 watt-hours, and the first electric launches which we built did as great a mileage as those made to-day. He also designed the first accumulator-driven tramcar, which I drove in the streets of Berlin after it had been made by the E.P.S. Company. Incidentally, it had a worm drive on the lines adopted by motor-car manufacturers many years later.

The first electric launch, built for the Duke of Bedford, was required to be fitted with a sail, and when Mr. Gorham and I were testing this near Millwall, a smart yacht came up the Thames, which rapidly overhauled us on every tack. As they passed us the owner said "Good-bye!" but when he was not looking we turned our launch into the wind and put on the electric power, with the result that on the next tack he found to his surprise he had gained nothing; and the same applied to the following. When we deliberately left the sail flapping in the air and repeated his greeting, "Good-bye!", I heard his remark: "What on earth have they got there?"

We also supplied the first submarine cells made for the "Isaac Peral," a squat vessel shaped like a carp, which, at the first demonstration, had an awkward experience.

Before lunch a number of journalists and others were battened down, and it was arranged to show them how the boat could be submerged. This it did effectually, but when the cylinders altering the displacement had been worked she did not rise, being firmly embedded in the mud. We on land were trying to get dredging tackle, as it was evident that something was wrong, when, to our great relief, she bounded up.

Someone had had the sense to make the captives run backwards and forwards, and the rocking action had released her; but none too soon, as the air was getting bad.

It was found that one man's hair had turned white from this ordeal.

The long life of batteries since obtained, reaching in some cases 30 years, is, in my opinion, as much due to increased knowledge of how they should be used as to any improvements in the plates themselves; and until some entirely new departure is made I do not think much more can be done with lead batteries, the construction of which must always be in the nature of a compromise. I was also for some time a director of Edison Accumulators, Ltd., and used a considerable number of nickel-iron cells for traction work and a few for yacht lighting.

While with the E.P.S. Company I obtained an order for the Prudential Assurance installation, since extended by Drake & Gorham to 8 000 lights, and the original plant is still working. I also did work for the Bank of England (for whom I acted as expert for 25 years) and others; so that when I had a difference of opinion with the Board as to my right to appoint my own staff I decided, in 1886, to concentrate on installation work, and was shortly afterwards joined by Mr. Gorham whom I had previously appointed works manager, thus founding the firm of Drake & Gorham. In order to keep in touch with batteries I worked with Elwell-Parker who had been given a licence by the E.P.S. Company, and when they were, against my advice, amalgamated as the Electric Construction Company, I arranged with Johnson and Phillips to make a French Planté cell developed by Dujardin. From this arises the name D.P., the origin of which has been a puzzle to many. These cells did well, and the E.P.S. Company did not attempt an action for infringement. Later, however, after a separate company had been formed at Bakewell, the D.P. Company, in common with most companies, adopted the Tudor type of positive plate. In this the metal is disposed to the best advantage, and, with the exception of America, the plate is now almost universal throughout the world. During the war the English branch of the German Tudor Company was sold, and, at my suggestion, a combined tender was put in by three existing companies, which was successful.

This tends to help standardization and co-operation, without which cheap production is difficult.

Like most people I have had my share of disappointments, amongst which I would mention the Nernst Electric Light Company, of which I was Chairman, though I managed to sell this to the Allgemeine Elektrizitäts Gesellschaft for a large sum before the bottom fell out of it. In this connection a director of the A.E.G. told me some time afterwards that the late Mr. Rathenau paid me a great compliment. He said I was the only Englishman who had ever got the better of him, as the rights which I had sold him for a large sum were soon afterwards rendered valueless by the introduction of the metal-filament lamp. As the A.E.G. were manufacturing Nernst lamps for my Company at the time and the late Mr. Rathenau had at his disposal the best technical advice, I did not feel guilty of sharp practice. As a matter of fact I had two stormy meetings with the Nernst shareholders, at which I had the greatest difficulty in getting the bargain ratified.

Another company of which I was chairman was the British Vitrite Company which held Swan's patents

for the universally-used vitrite lamp-caps. Although we had representatives of all the leading British lamp-makers on the Board, and orders for many millions of caps on the table, we were unable to make or buy the brass stampings for the price at which foreigners were selling the finished caps. However, the machines taken over by the lamp-makers enabled them to carry on during the war.

Looking back on over forty years of hard work, I cannot but feel that, to the pioneers, the electrical industry has not proved a gold mine, and that we should have made more money if we had taken up, say, soap manufacture. It would not, however, have been so interesting a life, and I hope that the next generation may benefit by the spade work of those who have preceded them.

SIR WILLIAM NOBLE.

The Electric Telegraph.

Several distinct Telegraph Companies were in operation in Great Britain up till 1870, and although at various times suggestions had been made that the Government should take over such an important public utility, the proposal did not mature until 5th February, 1870.

Since that date the development of telegraphy in all its branches has been most striking, and furnishes a strong case against those who contend that a State monopoly necessarily retards progress.

The process of making the different types of apparatus in use by the various companies as uniform as possible was immediately commenced, and within a few years the single needle had been displaced by the sounder on all important circuits, but was still kept in use on those of less importance.

In order to economize in line wires, methods were adopted to increase their carrying capacity as the traffic increased. Thus duplex working, which had been invented by Gintl in 1853, was introduced by the Post Office in 1873, while quadruplex working, independently devised by Heaviside in 1873 and Edison in 1874, was brought into use soon after 1876. In its practical form the quadruplex system was primarily an American invention: its subsequent development at the hands of the Post Office engineers eliminated a number of radical defects and practically a new system was evolved.

An outstanding invention prior to the transfer of the telegraphs to the Post Office, was that of the Wheatstone automatic system which, although patented in 1858, had not been used to any extent. The Post Office acquired four sets from the telegraph companies and these worked at a speed of about 80 words per minute. By 1880 there were 173 circuits working and the speed had been raised considerably above 80; eventually a working speed of 400 words per minute was reached. These sets were used mainly for the quick distribution of news items, which were accepted at a low charge.

Great improvements were made in the methods of repeating signals at intermediate points on long and difficult lines, and in the refinements in balancing on duplex circuits. All these matters contributed to the remarkable progress and ultimate perfection of the Wheatstone automatic system, which in 1919 numbered 676 sets in use by the Post Office.

The Hughes printing telegraph system, invented by Professor Hughes in 1855, was not used in the British Post Office service until 1889 when the Submarine Telegraph Company's system of continental cables was acquired. As regards design this instrument had remained practically unaltered in the hands of the Company, but was considerably modified in the few years following the transfer. It was made suitable for duplex working in 1893 by the late Mr. John Chapman, a Post Office engineer, and in 1894 the heavy driving weights and gear wheels were displaced by a small electric motor, making the instrument much more compact and portable, requiring only one man to lift it, whereas three or four were necessary previously.

Multiplex telegraphy which was first suggested in 1852 by Farmer, and afterwards developed by Meyer, Baudot and Delany, was destined to revolutionize telegraph practice. It owed its inception to the heavy cost of line wires compared with the cost of apparatus. The first multiplex system to be used by the Post Office was that invented in 1884 by Delany, and by its means as many as six operators could use the line simultaneously without interfering with each other. It was brought into use by the Post Office in 1886 as a single-curent system, i.e. working with one polarity, but was soon improved by the Post Office engineers, notably Messrs. J. Chapman and R. Hendrie, and made to work double current, i.e. with two polarities on each signalling key. Later on, it was duplexed by Mr. S. A. Pollock, a Post Office engineer, and gave very good results with eight operators sending at the same time, four working in each direction. The Delany system was fundamentally weak, and because of the high line speed required and the difficulty in maintaining adjustment its use was limited and eventually abandoned.

The adoption of a 5-unit code in place of the Morse "Dot and Dash" enabled a multiplex to be used on circuits with much lower line speed, and as the receiving apparatus had been arranged to record the signals in printed Roman characters there was no skilled reception, and no limitation of speed other than that of the mechanism and the skill of the sending operator. As developed by the Post Office the 5-unit multiplex is practically the system developed in France by Baudot and brought to this country in 1897 as a quadruplex-simplex set giving two working channels in each direction on one wire with a speed of 30 words per minute per channel, or a total of 120 words per minute per circuit. The output was not very much greater than that of an ordinary Morse quadruplex, but in 1905 it was successfully duplexed by Mr. A. C. Booth, a Post Office engineer, giving 6, 8, 10 and 12 channels, where previously the French Administration had only

3, 4, 5, and 6 channels respectively. The successful duplexing of the Baudot system practically revolutionized telegraphy because of the very large increase in the carrying capacity of wires and in the output per operator. The 12-channel set working on one circuit between London and Birmingham has carried more than 800 messages in one hour and more than 8 000 messages in one day of 12 working hours. The merits of the duplex Baudot have been universally recognized by telegraph inventors and the latest developments in telegraphy, with the one exception of the Creed, are all based on the duplex Baudot of the British Post Office.

It is not practicable to mention in detail the vast number of improvements which have been effected in telegraph systems and methods since the State assumed control; but one of the outstanding achievements was the design of the multiple intercommunication switch by Mr. T. F. Purves. It was brought into use at the Central Telegraph Office, London, in 1902, with the result that the transmission of telegrams from one part of London to another was greatly expedited, while at the same time it eliminated over 50 000 sent and received messages per day at the Central Office with corresponding economy in staff for operating.

In conjunction with this scheme central-battery systems of telegraphy, simplex and duplex, were devised, although it was not until 1906 that they were used to any extent by the Post Office. In 1905, Messrs. J. Fraser and C. J. Mercer, Post Office engineers, made suggestions which resulted in a satisfactory central battery system for general use throughout the country. For simplex circuits a modified form of the ordinary pony sounder, known as a polarized sounder, was designed by C. C. Vyle in 1906 to enable positive and negative currents to be used directly through the sounder.

The great advantage of central battery working is that it obviates the necessity for batteries at outstations where often space is limited and facilities for battery cleaning are unsatisfactory. The abolition of batteries results in a considerable saving in annual charges: up to the present time conversions to central battery working have resulted in the recovery of over 40 000 primary cells. Moreover, the adoption of this system considerably simplifies the apparatus at outstations, e.g. on simplex circuits, all that is required is a single-current key, a polarized sounder and a small condenser of fixed capacity, thus dispensing with the local and main batteries, the relay and the galvanometer.

It has always been the practice of the Post Office to give inventors every possible encouragement and assistance in the development of new ideas, and there is no doubt that this policy has been fully justified by results, as is indicated by the development of the Creed, Gell, and Murray apparatus. The Creed is an adjunct to the Wheatstone system and avoids the delay and cost of translating the printed "Dot and Dash" of the Morse Code. It has proved to be economical and expeditious. Murray originally devoted his attention to an automatic system on Wheatstone lines but using a 5-unit code and page-printers for the received message. After the success of the duplex Baudot, Murray developed his multiplex system in which the main features of the Baudot duplex were utilized. He, however, reintroduced the Carpentier method of transmission by tape prepared by an alphabetical keyboard perforator.

In 1898 Gulstad of Copenhagen invented a modified form of polarized relay known as a "vibrating relay," the use of which has enabled much greater speeds of working to be obtained on underground lines and on submarine cables, resulting in some cases in the release of "Repeaters" which are costly to install and maintain. The original instrument was arranged for simplex or for bridge duplex working. The Post Office engineers have modified this relay and made it suitable for differential duplex circuits, with very satisfactory results.

During recent years the Post Office has made a close investigation of the various types of primary batteries with the result that an improved form of the ordinary porous pot Leclanché cell has been introduced, taking the place of the Daniell, bichromate and other primary cells for telegraph purposes. It was found that finely powdered manganese dioxide was much more efficient as a depolarizing agent than the coarse-grained variety ordinarily used. In some circumstances it was found to be more advantageous to use manganese chloride solution in place of the sal-ammoniac, as apparently no free gases are given off with the former. This permitted the cells to be sealed, thereby retarding the evaporation of the solution, so that the cells required less attention.

The displacement of primary batteries by secondary cells in all large offices, and the extension of the universal-battery system with its specially designed switching arrangement has effected considerable economy in prime cost, maintenance and space. The use of generators for telegraphic purposes has been investigated, but the results, so far as this country is concerned, have not been such as to show that any great economies or advantages would accrue from their universal adoption.

The British Post Office has always been pre-eminent in its methods of line construction, which are probably the best in the world, its work being recognized as the standard by all Colonial Governments. As regards open telegraph lines the main advances in the past 50 years have been the use of copper wires for main lines and bronze wire for local lines in place of iron wire; and the introduction of the "Cordeaux" screw insulator invented by Mr. J. Cordeaux, a Post Office engineer.

Turning to underground construction, it is interesting to note that the earliest experimental telegraph lines in Great Britain were of copper wire covered with cotton or hemp varnished with insulating substances and laid in iron tubes. Subsequently, and for a large number of years, underground lines were of copper wire insulated with gutta-percha and laid in grooved boarding. After the transfer of telegraphs to the State, the underground lines were confined principally to the large cities and consisted of gutta-percha covered copper wires laid in cast-iron pipes. Although the devastating effects of severe storms on open telegraph lines emphasized the value and necessity of an underground system, yet for a number of years its complete adoption could not be

justified on economic grounds. The number of gutta-percha covered wires that could be accommodated in a pipe was comparatively small, e.g. a 3-in. pipe could take only 70–80 wires, so that any considerable extension of the underground systems involved the construction of a large number of pipe lines at a prohibitive cost. The whole aspect was changed, however, by the introduction of paper-core cables, and although the first long-distance cable of this type laid between London and Birmingham in 1898 had only 76 conductors, the subsequent developments have been such as to enable cables to be made so compact that a 3-in. pipe will carry as many as 2 400 conductors.

The following approximate mileage figures will perhaps convey some idea of the growth of the telegraph system since 1870:

Telegraph mileage	1870	50 000
,, ,,	1920	272 000

Of the latter figure 108 000 miles are underground, and 150 000 overhead, the remainder being submarine.

MR. C. H. WORDINGHAM, C.B.E.

I have been asked by the President to write a few words reminiscent of my connection with Dr. John Hopkinson and of the state of things in the electrical world at the time.

I was articled to Dr. Hopkinson in 1885, but he first came into my field of vision at an earlier date in connection with his prediction that alternating-current machines could be run in parallel. This prediction had been verified in practice by Professor Grylls Adams at the South Foreland on some lighthouse machines, and I was one of the King's College students chosen by Professor Adams to assist him at the South Foreland in experiments which were being carried on concerning the relative merits of gas, oil and electric light for lighthouse purposes. The machines which had run in parallel were used in these experiments.

It was not until some years after I went to Dr. Hopkinson that he became connected with King's College, and in my time his experimental work was done in his own laboratory in Victoria-street. In this laboratory I spent much of my time and carried out many of his experiments in connection with magnetism and specific inductive capacity.

The historical paper which he wrote in conjunction with his brother Dr. Edward Hopkinson on Dynamo-Electric Machinery was written at this time, and I well remember how carefully all the calculations were checked. This paper was probably the foundation of scientific dynamo design.

Another epoch-making paper, though of a very different character, given at this time by Dr. Hopkinson was his Inaugural Address delivered on 4th November, 1892, to the Institution of Junior Engineers, in which he laid down the principles governing the cost of production and those which should govern the method of charging for the supply of electrical energy; I venture to think that in spite of the enormous amount of discussion on these subjects which has taken place since 1885 very little has been added to what he then set forth.

On the expiry of my articles with Dr. Hopkinson I left him for a time, rejoining him in 1892 as his assistant, in order to supervise on his behalf the erection of the Manchester and Whitehaven generating stations. The Manchester undertaking attracted a very large amount of attention at the time on account of the use of the 5-wire system. It is doubtful whether Dr. Hopkinson ever received the credit that was due to him for this essentially bold step, nor for the very real success which undoubtedly attended it. When the work was started, nothing had been heard of 200-volt lamps, and he was able by the 5-wire system to attain nearly all the advantages of the higher pressure which the 200-volt lamp afterwards made possible, without making the sacrifices of efficiency of arc lamps and incandescent lamps which were entailed by 3-wire, 200-volt systems. If these higher-pressure lamps had not been invented, the Manchester example would have been copied in many towns, and had the system been better understood there can be little doubt that many of those undertakings which changed over at great expense from 100 to 200 volts would have slipped in two additional wires in their networks and defied those obstructive consumers who held out against having their installations changed over to the higher pressure.

The 5-wire system was never properly apprehended by the electrical public, and troubles due to faulty mains were erroneously ascribed to the system of distribution.

An interesting point which the Manchester and Whitehaven systems had in common was that they were, I believe, the first to have the middle wire of a multiple-wire network connected solidly to earth. It was this solid connection unquestionably which caused nearly all the troubles in the early days with the Manchester mains. Instead of the negative pole assuming earth potential automatically and no current worth speaking of flowing through the insulation of that conductor, there was maintained between the negative and earth at all times a pressure of 200 volts which forced the current through the dielectric. This dielectric being rubber, and, like all rubber, porous, electric osmosis forced the water into the pores, forming bubbles of liquid which gradually grew until they burst and made a hole in the rubber.

In the early days of which I write, "the battle of the systems" was in full swing. Not only were there the two main camps of high-pressure alternating and low-pressure direct (or continuous as it then had every right to be called in all senses of the word as compared with its high-pressure rival), but the Oxford system of parallel operation of high-pressure direct-current motor-generators in substations automatically started up was making a bid for favour, and the system of charging in series a number of batteries distributed over the area could hardly be said to be dead.

It is hardly credible that the generators at Manchester,

of which the largest had a capacity of 240 kilowatts, were looked upon as tremendous machines and referred to as "Jumbos."

To the same period belong the early days of the London Electric Supply Corporation, on whose staff it was my privilege to be. Well do I remember the introduction of meters on the system of that Company. At the time I joined the Company, of which Ferranti was the presiding genius (accent on the *genius*), namely, in 1889, there had been only some two or three dozen meters put out experimentally, and they were of the mercury type with three connecting bolts projecting from the bottom. These bolts fitted into spring contacts fixed in oak boxes, the arrangement being such that a meter could be changed in a few moments, it being assumed that their constitution was so delicate that each instrument would often want changing. These pin contacts for currents up to 100 amperes, combined with the characteristics of the meter, did not admit of the use of the oak boxes for refrigerating purposes.

The results of the introduction of meters were most remarkable, some consumers finding their accounts drop to a third of their previous value and others finding them trebled. I need hardly say that the latter class of consumer was not impressed with the accuracy of electrical measurement, and I have most vivid recollections of stormy interviews with consumers whom I tried to convince that my tests were accurate. It is only fair to the meters to say that I demonstrated clearly that some of the largest consumers had no regard whatever for the truth in stating their consumption.

The recollection of the experience of those early days gives rise in my mind to an old man's indulgent smile when I hear a contract rate per lamp advocated as the newest thing in panaceas for producing revenue from an electrical undertaking. There is only one true system of charging and Hopkinson is its prophet; he introduced it in the two early stations I have mentioned above, and I had the experience of educating successive Electricity Committees, to say nothing of consumers, in its mysteries for eight years, so I ought to know.

Perhaps my most vivid recollection of this period is the mental picture which I have of Ferranti amid the ruins of the Grosvenor Gallery on the morning succeeding the fire. Before the day was out he had invented a safety device which would make an accident similar to that which caused the disaster impossible, and it fell to my lot to make the first one. In those days we used to hold rubber-insulated 10 000-volt cables in our hands and wave them about when testing transformers; if I had known as much of rubber then as I learnt afterwards in Manchester, I do not think I should have had quite so peaceful a mind when testing. A little later we used to measure the current in the 2 400-volt mains by standing on insulating stools and turning the ammeter's torsion head, which gave a little static spark into one's finger every time one touched it; I remember that anyone standing on the ground who offered to hand one a tool at the time was unpopular.

One word in conclusion about Hopkinson himself. It was a wonderful privilege and an education to work with him. His mind was so clear and everything he said so directly to the point that one soon grew accustomed to be extremely careful not to make foolish remarks to him. Anything more crushing than his "Cle-arly" if one made some observation that did not require any large amount of demonstration of its truth, I have no wish to encounter. In the witness box his "Yaas" was more convincing than a dozen asseverations. He was extremely large minded and, while expecting a plenteous measure of hard work from his staff, he was very agreeable to work with and always reasonable and equable in his manner. Few realize, I think, what an extraordinarily fertile mind he had in invention. Most of his patents were acquired by the Westinghouse Company, and engineers of to-day would be astonished to know how many of the appliances in everyday use owe their initial invention to Dr. John Hopkinson. High as his reputation is, much more would have been said about him had the full extent of his work and genius been more widely known, but he never advertised nor courted popularity.

MR. LL. B. ATKINSON.

When I was with our President last Monday, just before he had this unfortunate attack of lumbago which has kept him from being with us, he asked me if I would say a few words at the close, collecting in some way what might have been said during the meetings. I shall give you, therefore, less of my own personal reminiscences, but rather tell you some of the thoughts that have come into my mind while we have been here.

I think all will agree that this series of meetings, which it was the happy idea of our President to hold in commemoration of our fiftieth anniversary, have been a great success. To listen to the lecture by Professor Fleming and to see all those original pieces of apparatus which the founders of our science had in their hands, and to listen to the short—all too short—reminiscences personally given by many of the early pioneers, has been, I suppose, to everyone of us an immense pleasure. For the moment they have carried us, as Dr. Eccles said yesterday, into another age, an age, however, which although so far off is so near to our present age that the men, or many of them, are here still who took part in that original age.

We have had from Professor Fleming once again retold the wonderful story of those discoveries of Faraday; we have with reverence seen and touched the coils, the wires, the tape, the string and the paraffin wax—all the raw material of the early electricians; and we have had the opportunity of seeing in the next room, in all the glory of varnish and paint, which I am sure was never on them originally, some of the original apparatus which figured in the foundation of our industry, historic remnants which will be of interest

as long as civilization lasts. It is well that on the fiftieth aniversary of the first meeting of our Institution, we, and especially the present generation of electrical engineers, should thus collect and visualize a picture of the past, because we may be, and I believe we are, at the beginning now of another age, a tremendous era when the atom and its energy will probably replace all those generating appliances we have been looking at.

As the last of those who will speak to-night, I shall first say a word or two on some who were of this age but who have gone and who are not, therefore, with us to-night. One of those was Thomas Parker. I only speak from hearsay as to his beginnings, but I believe he was by turn iron moulder, travelling showman, mesmerist and then electrician. It is interesting to recollect that several men, early prominent in the electrical world, were showmen. The public desired to see something of the wonders of electricity, and these men had to supply the need. One such man, whom I remember well, was Mori of Leeds, who had a small and confused little shop in the Corn Exchange. He possessed some Wilde and Ladd generators with separate exciters on the top, with which he used to demonstrate a Serrin arc lamp. I remember all this because I used to go and see it with an old uncle of mine, when I was about 15 years of age.

Parker, I think Colonel Crompton will agree, was one of the first to appreciate that the dynamo was a piece of mechanical engineering, and his machines with armatures with one layer of wire and the armature positively driven from the shaft were beautiful pieces of machinery in the early days.

There is another pioneer I should like to mention, Professor Hughes. We have heard his name mentioned in connection with the electric telegraph. He was a rather extraordinary person. He might be seen with his wife almost every evening in Pagani's restaurant in Great Portland-street. He used to come down to the Institution and give us lectures and addresses with simple pieces of apparatus composed of cork and sealing wax, with which he took us into the depths of the atomic nature of the materials he was showing. I remember as a young man thinking that there was nothing more marvellous or magnificent than Professor Hughes's lectures.

Nor can I refrain from mentioning Ayrton. A good deal of fun was made of the fact that every invention and every development as it arose was claimed by him on his own behalf and Perry's as their invention. The fact is it was really true. It was Maxwell who once wrote that the electrical centre of gravity of the earth was in Japan. That was when Ayrton and Perry were Professors in the University of Tokio and had commenced to tear electricity from the textbooks and bring it into practical life.

During the course of the Commemoration Meetings there has come to me with a clearness I never realized before, as Colonel Crompton said, how tremendously ignorant the early workers were. I had never realized, until some of our friends were speaking yesterday and to-day, all these tremendous difficulties, because my own training was so different. In Crompton, Kennedy, John Raworth and Kapp, for instance, we have examples of well-trained and expert civil and mechanical and steam engineers who had to begin to learn electrical science in the middle of professional and commercial life. An opposite group were Hopkinson, Professor Forbes, Sir Oliver Lodge and Sir William Thomson, men of university and mathematical training who knew the mathematical theory of electricity as it then existed perfectly well, but who had very little of that practical knowledge of engineering which proceeds from actual touch with things. Then again we have another type. Ferranti had very little training in the strict sense of the word. The same is true of Mordey and Ravenshaw. Sir Alexander Kennedy spoke of the 112-kW machines in the Westminster Company's station at Millbank. Ravenshaw designed those machines, and my then firm built them. Ravenshaw, who was one of the cleverest early designers of machines in this country, is still working hard in the electrical world and has done a great deal of useful work. He was one of the pioneers. These men—though Mordey had some knowledge of telegraph engineering—trained themselves. Ferranti trained himself, I believe, and incidentally he trained a good many others in the operation of electrical apparatus.

I compare this with my own introduction to electricity. I represented a new school that was coming in. Evershed told us yesterday of his first experiments with a telephone of his own making. When I was 13 years of age I remember being at the house of a Mr. James, whose son was a school friend of mine. Mr. James was one of the chief cashiers at the Bank of England, but he was also a very clever mechanic. He had read the description, published in the "English Mechanic," of the Bell telephone. I was at his house one evening when he had completed an apparatus designed on those lines, and we had the telephone connected from the drawing-room to the dining-room and we all listened to the speech. I thought it was very amusing, but was too young to appreciate it, which Evershed did.

Shortly after that—that would be about 1877, when I was still about 14—I made a set for myself, and the first lecture I ever gave in my life while still a schoolboy, was on the telephone. At 14 I studied physics and chemistry at school in a good laboratory, and at that age I could use a lathe, a soldering iron and most tools, and at 17, during my last year at school, I attended the City and Guilds evening classes under Prof. Ayrton. Those classes were very curious. We had, I suppose, an hour in the laboratory and an hour's lecture. In the laboratory Ayrton was round among the students, who were of all ages and depths of ignorance. I was probably the youngest. There were telegraph engineers and instrument makers, men up to 60 years of age, all wishing for knowledge of the new art. Ayrton bustled about among the students in the laboratory answering questions, most of which did nothing but display the profound ignorance of those who asked him. Guy Fricker was there, and Rechenzaun, and my old friend Esson, who used to question Ayrton nearly to death. Esson reminded me recently of how one night, when Ayrton could stand it no longer, he said "Oh, be quiet; it is all in Maxwell." There were also Mather, Walmsley

and Cockburn, who are all still alive and engaged in electrical work. These three were the demonstrators, though, I now suspect, at that time not knowing much more than the students. They had to struggle with the students and struggle with Ayrton, who pushed along at a tremendous rate. For the first time in teaching laboratories definite experiments were fitted up on the benches with instructions, so that time was not wasted by students, who did not know what the experiment was, trying to set it up. There was a Brush 6-arc lighter, a Gramme machine of about 3 kW, a gas engine by Crossley, and a transmission dynamometer. Many of the discoveries of the early days were made there by those students and were published in the Institution *Journal* and elsewhere by Ayrton and his colleagues. As for the lectures, there was no syllabus, or, if there was, it was never adhered to. We had lectures on the evening's experiments or whatever Ayrton was just then working at, and blackboard and algebra, of which more than half the students were entirely ignorant. But for those who could understand the lectures, there was being given priceless information for 5s. a term or 15s. the session.

It was in this way that I came into electrical engineering. Trained by the age of 14 in chemistry, tools and simple electricity, by 18 years of age, before I left school, I had been under Ayrton and had taken the first prize—£5 (a lot of money to me in those days)—and a silver medal in the technological examination in electric lighting. I had read Fleeming Jenkin's electricity and understood it. He knew all about absolute measurement and made it clear in his book. It is said there were no books at that time, but there was Fleeming Jenkin's, and for those who could understand him it was all there. Then on the advice of William Siemens (afterwards Sir William) I had three years at King's College, and by 19 years of age had read Faraday's electrical researches and had Maxwell's treatise, of which I understood the meaning, if not all the mathematics. Then I passed through a practical training in a locomotive works. So when, in 1885, I was under Trotter and, above all, under Ravenshaw, I came into the electrical world with a complete training in physics and electrical science as well as in engineering knowledge.

But imagine the electrical world as it was then. We have spoken of the differences which existed in those days, when three different electrical languages were being spoken. I remember Hopkinson's lecture at the Institution of Civil Engineers when, by considering the equation of motion of two parallel connected alternators, he proved by a simple series of equations that under certain conditions the motion was stable and that they could run in parallel. He treated it simply as the equation of motion of two moving bodies with certain forces between them—it might almost as well have been the sun and moon. Nobody believed him, because the only alternators at that time that had any practical vogue were the Siemens alternators, and everyone knew it was practically impossible to run them in parallel. Until it had been proved in practice, this language of equations convinced nobody.

I remember a discussion on transformers at the Institution of Electrical Engineers, when Kapp gave a paper on the subject. Professor Forbes jumped up and put a few differential equations on the board which, he said, gave the whole theory of transformers and there was nothing more to be said ; but he was speaking a language which no one who was making transformers understood. At the beginning of alternating-current practice, Blakesley showed us by graphic vector algebra how to find out what took place in alternating-current circuits, but it was beyond the practitioners and, besides, the alternators then existing did not give sine waves, which were required for the theory.

I lay stress on all this because it has come to me so clearly during the last two days—the realization of this great difference between the three groups of men who were then working in the industry, which, when realized, helps to explain much that occurred. As Colonel Crompton said at the beginning, those were indeed joyous days. An experimentally discovered fact always will, I believe, give more pleasure to the discoverer than a deduction from theory, because if he makes the discovery as an experimental fact he feels he has done something, whereas if it is deduced from theory he only feels, " Well, after all, it was always there, and all I have done is to demonstrate it."

Team work, as Colonel Crompton has said, was the lesson and key-note of the day, and my last word is that it is still the key-note and has been from the start the key-note of the Society of Telegraph Engineers and the Institution of Electrical Engineers.

Mr. G. W. Partridge : I desire to ask the Institution to accept, in remembrance of the event now being celebrated, the apparatus which I exhibited.

The Chairman : I am sure that the Institution is very much indebted to Mr. Partridge, and that they will accept these articles with much pleasure and gratitude.

The Chairman : Before I close the meeting, I suggest that we should send a message to the President wishing him a speedy recovery and telling him that the Commemoration Meetings have been a great success, and that the only misfortune has been his inability to be present.

The suggestion was agreed to with acclamation, and the meeting terminated at 10.5 p.m.

In addition to the addresses given at the meetings, the following written contributions were received : –

MR. O. H. BALDWIN.

At my early home in Newark, New Jersey, Weston and Edison first commenced their electrical work, and, as a boy, I visited both their factories and saw one of the first Edison incandescent lamps and also the first arc lamp and dynamo made by Weston. Edison was well known to the public in 1877 as the inventor of a system of multiplex telegraphy. In 1878 with three of my friends a telephone exchange was established between our houses. We made our own telephones from designs published in the technical papers of the time; we also made our own batteries and strung our line wires, and this was my introduction to practical electricity.

After the usual engineering training in one of the American technical colleges, a billet was offered me in the Westinghouse Co. in the early part of 1886. The Company had been in existence then about 2 years, and was competing principally with the Edison Co. The Edison Co. controlled the 3-wire patent in the States, and the Westinghouse Co., looking for a new method of distribution which did not infringe the Edison patents, purchased the Goulard and Gibbs transformer patents, and by 1888 had developed a single-phase dynamo and were manufacturing transformers from 5-light to 50-light capacity. My work from 1886 to 1889 was to install and operate engines and dynamos manufactured by the Westinghouse Machine Co. and the Westinghouse Electric Co. respectively.

In the year 1888 the Metropolitan Electric Supply Co. of London had one electrical station in operation and were contemplating the building of four additional stations. The directors decided that a contract for one of these stations should be placed with an American firm in order to derive benefit from American experience. This broad-minded policy was followed and a contract was made with the Westinghouse Electric Co. for the equipment of their Sardinia-street station.

The contract included all the steam and electric plant within the station walls, and under its terms the Westinghouse Co. were to operate the plant for 6 months or until taken over by the purchasers. The boilers, piping, engines, switchgear and dynamos were erected by a contracting firm allied to the Westinghouse Co. and the work was completed in October 1889. My position was that of operating engineer during the period of maintenance, and my stay in London was assumed to be about 7 months. This contemplated limited sojourn in London has by various changes been extended to 32 years, and accounts for my presence at this aniversary.

Mr. Frank Bailey was chief engineer of the Metropolitan Electric Supply Co. and was the first English engineer I had the pleasure of meeting, and I am grateful to add that we have been good friends ever since.

The Sardinia-street station enjoyed the distinction of being one of the first electric generating stations equipped with Babcock and Wilcox boilers, and the steam-pipe drawings and boiler arrangements were prepared under the personal supervision of Sir James Kemnal.

The engines were of the Westinghouse vertical compound type with a single piston valve for both cylinders, and the dynamos were all on the floor above, driven by belts from the engine flywheels. The dynamos were designated as 125 kW capacity, 1 000 volts, single-phase, 133 periods. They were excited from three exciters, each separately driven. The alternators were not connected in parallel.

The switchgear was very simple and by a proper combination of switches any feeder circuit could be connected to any of the alternators. The scheme was standard at that time with the Westinghouse Co., and it had the great advantage of localizing a fault to the circuits being fed from one alternator. We had no circuit breakers in those days and all of our protection was by fuses.

Practically the whole of the steam piping of the first Sardinia-street plant was of cast iron. It would seem odd now to see a line of steam piping up to 12 inches diameter of cast iron, and it has always appeared strange to me that it gave us no anxiety; leaky joints at the flanges were our principal trouble, although we did have one cracked pipe due to water. So far as I am aware, there never was a serious accident of any kind at the Sardinia-street station. Ultimately there were 10 machines installed all practically alike, and the total capacity of the station when the Westinghouse second contract was completed was about 750 kW. There is no vestige of the station left now and the middle of Kingsway marks the line on which the old Sardinia-street chimney stood.

In 1896 the business of the five operating stations of the Metropolitan Electric Supply Co. outgrew the station capacity, and meanwhile a large proportion of the engine-driven sets of all five had been replaced by turbo-generators of the Parsons type. The Company was obliged to leave the congested area of London and decided to build a large station at Willesden Junction. The Westinghouse Co. supplied the first generating sets for this station. The engines were of the marine type, compound, non-condensing, each directly connected to a two-phase generator, 500 volts per phase. An exciter was mounted on the end of the generator shaft. The periodicity was 60 and the speed 116 r.p.m. The capacity of each unit was 1 500 kW. We had considerable trouble with the sets at first.

Here were the conditions that puzzled us for several weeks:—

(1) With governors in action and on light load two of the machines would stay in parallel on one of the two phases, but would commence to see-saw when the second phase was connected.

(2) Two sets would work perfectly in parallel with one or two phases connected, if one governor was put out of action and controlled by the engine stop valve.

(3) The sets ran perfectly together when both governors were out of action and the engines were controlled by their respective stop valves.

Under the conditions mentioned first, it was most interesting to stand behind the switchboard and watch

the busbars. The busbars were composed of strips of copper $\frac{1}{4}$-inch thick and $2\frac{1}{2}$ inches wide supported by brackets. There were six strips in each busbar. As the machines commenced to see-saw when paralleled, and as the synchronizing current increased, the bars would regularly breathe with each swing of the two sets, the greatest amplitude of the movement would be at least $\frac{1}{8}$-inch in the case of the two outside bars, the point of greatest movement being midway between the supports. It was a curious thing to watch and gave one a most uncanny feeling. It also showed the necessity of bracing coils subject to heavy currents, and if this repellent action between conductors had been better realized many generators and transformers manufactured since that day would have been saved a breakdown.

The synchronizing current producing the described action on the busbars was naturally far beyond the adjusting capacity of the circuit breakers, and during the experiment it was necessary to hold the circuit breakers in forcibly. It was, of course, imperative that the machines should run properly in parallel, and the trouble described was remedied by adding weight to the armatures, after which no further difficulty was experienced.

As previously stated, the machines generated current at 500 volts per phase, and to bring the current into London step-up transformers of the Berry manufacture were employed by the Metropolitan Co. and the voltage raised to 10 000 volts. It was at Willesden that I first had the pleasure of meeting our President, Mr. Highfield, who was for a long period the resident engineer.

About the time (1897) that these sets were in running order, electric traction was developing. Parliamentary restriction had been modified. Glasgow, Bradford, Plymouth, Bristol, and the London United Company all were building or had started to build. Steel mills, collieries and large works commenced to install the electric drive, and electrical machinery rapidly became fairly well standardized. As a result of the great demand for electrical machinery of all kinds, a tremendous growth of manufacturing facilities took place. Between 1898 and 1905 the British Westinghouse Co. was created and their works built at Trafford Park, and all the electrical manufacturing works were increased, some of them more than doubled.

The most important changes in central station equipment during the past 20 years are the replacement of reciprocating engines by turbines and the complete revolution in switchgear. When mentioning switchgear it was Reyrolle personally who, with a helper, remade our simple Pittsburg switches and gear for the Sardinia-street station in 1888–9, and it was the Sardinia-street contract which started him in the switchgear business. One of the striking things about central station equipment of the present day is the way in which circumstances have increased the proportionate cost of switchgear and lowered the proportionate cost of the prime movers and their generators. When considering the subject of prime movers, the fact cannot be escaped that without the work of Sir Charles Parsons modern large-power central stations would be almost impossible, and a tribute from the whole world is due to his leadership, his mathematical knowledge, and his engineering skill.

The Institution has reason to be content with the results achieved during the past 50 years, but engineers, from the nature of their profession, are building always for the future, and I should like to mention in connection with the future a subject that we must acknowledge to be the greatest unsolved problem of the world to-day. I suggest—though the suggestion is not original—that it is an engineering problem, or at least might be made such. I refer to the industrial problem, the problem of capital and labour, and in my 32 years of residence in England this problem has changed greatly and much for the worse, not only in Great Britain, but in every civilized country. The problem has as many phases as two alternating-current machines coupled together electrically but without sufficient synchronizing power to hold them in step. Mr. Carman, late President of the American Society of Mechanical Engineers, chose this as the subject of his inaugural address. I will quote three short paragraphs from this address and would ask you to note that while he refers to the conditions over there, how closely his words apply to our British conditions.

"Thus we had, growing side by side, two distinct organizations of classes; one, Industry or Capital, the other, Labour Unions or Labour. Not only have both of these organizations increased in size, but each has combined and federated with others of its kind, until both as unwieldy—overgrown, unable to control or direct their followers—each seeking the advantage over the other, and both actually taking advantage of the great consuming class, the Public.

"We have still another complication, a third party—the Government—attempting to direct the other two, and the result is more deplorable than ever.

"Since the Government is administered by a class which we in America call 'politicians' and since each class has its own interests to protect, it follows that no one class should attempt to control the other two."

President Carman considers that this problem can be solved, and he suggests that engineers should solve it. Could not we engineers in England assist in bringing about a solution? I believe that engineers, standing, as they do, between Capital and Labour and between the general public and its safety, are competent to do so. From their education, their training and their sympathy with all classes, they are well fitted to work out a solution. May I be pardoned for suggesting that this Institution on completing its 50 years of hard and successful work might commence its second half century in an earnest study of this subject. It does seem possible that along this path a result even greater than the Institution's past can be achieved.

MR. GEORGE BALFOUR, M.P.

Post-war Legislation and its Effect on the Electricity Supply Industry.

Before I deal with the subject of post-war legislation it might be convenient to mention the general Acts of Parliament relating to the supply of electricity in pre-war days and also briefly to describe the history of electricity supply in the United Kingdom up to the introduction of the Electricity (Supply) Bill, 1919. The pre-war Acts are :—

Electric Lighting Act, 1882.
Electric Lighting Act, 1888.
Electric Lighting (Clauses) Act, 1899.
Electric Lighting Act, 1909.

And

Electric Lighting (Scotland) Act, 1890.
Electric Lighting (Scotland) Act, 1902.

In addition, the following Acts of Parliament deal with special matters in the Greater London area :—

London Overhead Wires Act, 1891.
London Electric Lighting Areas Act, 1904.
London County Council (General Powers) Act, 1906.
London Electric Supply Act, 1908.
London Electric Supply Act, 1910.

If the above statutory provisions were not an ideal code of Acts, they were, generally speaking, sufficiently comprehensive and elastic for practical purposes.

The electricity supply undertakings established up to the end of the 19th century were of modest size and the supply areas were small, which was largely due to electricity being regarded as a lighting agency. At the end of 1900, 518 Provisional Orders, granted by the Board of Trade and confirmed by Parliament, were in operation. Of the undertakers, 354 were local authorities and 164 were companies.

The active development of the supply of electricity for power purposes on a large scale roughly dates from the beginning of the present century, and between 1900 and 1914 practically all the special Acts under which the 29 power companies operate in this country to-day were passed, and in these Acts the power companies were granted the right in perpetuity to supply electricity for power purposes, and in bulk to undertakers, throughout large areas. During this period great improvements were made in the generation and distribution of electricity, chiefly as a result of the development of the steam turbine, which automatically forced other advances in electrical engineering practice, and made it commercially possible to concentrate large and efficient generating units in steam-operated power stations, transmit electricity over wide areas and long distances, and supply power on terms which attracted consumers.

It was during the last 4 years of this period (1910 to 1914) that a remarkable growth was noticeable both in demand and facilities for supply, chiefly owing to the proved reliability of moderate-sized steam-turbine plant. Large areas under the control of power companies which had remained undeveloped were actively taken in hand, and by the year 1914 there were very few of the larger electricity supply undertakers in the country who had not under construction or actual consideration large additions to their generating stations and distribution systems. It is, I think, true to say that, but for the outbreak of war, the years 1914 to 1920 would have disclosed a remarkable and widespread extension of supply, resulting in a complete revolution in the position of the electricity supply industry throughout Great Britain.

Almost immediately on the cessation of hostilities, electricity supply undertakers were ready to go forward with the development which was held in abeyance owing to the outbreak of war and, had they been left alone, rapid progress would have been made. Unfortunately, at this time all progress was blocked by the announcement of Government interference, including refusal to permit generating stations to be erected, and forecasted fantastic legislation. This legislation ultimately took the form of the Electricity (Supply) Act, 1919.

The passing of the Act of 1919, the revolutionary provisions of which were certainly not, as far as I have been able to ascertain, demanded by the taxpayers of this country or the electricity supply industry, was preceded by long reports by : (1) the Electrical Trades Committee appointed by the Board of Trade, (2) the Coal Conservation Sub-Committee of the Reconstruction Committee, and (3) the Electric Power Supply Committee also appointed by the Board of Trade. The function of the last Committee was : "To consider and report what steps should be taken, whether by legislation or otherwise, to ensure that there shall be an adequate and economical supply of electric power for all classes of consumers in the United Kingdom, particularly industries which depend upon a cheap supply of power for their development."

The Electric Power Supply Committee reported on 29th April, 1918, and the following are the main features of the recommendations of the Committee :—

(1) The setting up of a new body to be called the Electricity Commissioners in whom would be vested powers for regulating, encouraging and controlling the generation and distribution of electricity in the United Kingdom.

(2) The dividing up of the United Kingdom into Electricity Districts technically suitable for the economical generation and distribution of electricity.

(3) The setting up of a District Electricity Board for each of the Electricity Districts, whose function it would be to be responsible for the generation of electricity in each District, to purchase all generating stations in the district (other than private generating stations), to establish new generating stations, and to own and control all main transmission lines in the district. These District Boards were to make no divisible profits and be financed by funds raised with Government assistance except where it was desirable and practicable to finance the Boards locally. The existing electricity supply undertakers might retain their distributing rights but should take their supply

in bulk from the District Boards, and provision was to be made for controlling the profits of those undertakers so as to ensure a cheap supply of electricity to consumers.

The above recommendations, without the addition of a touch of statesmanship to protect the patient public, were embodied in the Electricity (Supply) Bill, 1919, which was introduced into the House of Commons on 8th May, 1919. There is, I think, no doubt that the Government scheme, as disclosed in the Bill, would eventually have led to the complete nationalization of the business of supply and distribution of electricity in this country. Fortunately, the Bill was considerably altered in Committee of the House of Commons and also in the House of Lords and, before the Bill emerged as the Electricity (Supply) Act, 1919, it was shorn of the most objectionable provisions, including the clauses relating to the compulsory setting up of District Boards. Put briefly, all the compulsory powers in the Bill of 1919 disappeared, including a proposal that the Electricity Commissioners were to be given authority to make advances to District Boards and authorized undertakers up to a total of £25 000 000. The Act, however, still contains a provision that the Minister of Transport can spend £20 000 000 for erection of emergency generating stations, main transmission lines and other works. When the Bill was before the House of Commons Committee, the Government accepted an amendment providing for voluntary co-operation among electricity supply undertakers in each district under a body to be called the Joint Electricity Authority for the District, but in the Act there are no provisions to enable such an Authority to raise capital for the purchase or erection of generating stations and transmission lines.

The Government were very unwilling, even in the face of the strongest opposition, to modify the Bill of 1919, and, when the Bill was in the House of Lords, the Lord Chancellor stated that a supplementary Bill would be introduced covering the parts jettisoned by the Government. The Government have, in this connection, displayed rare persistence, for they have introduced into the House of Commons no less than three futile Bills to amend the Act of 1919. These three Bills were the Electricity (Supply) Bill, 1920, the Electricity (Supply) (No. 2) Bill, 1920, and the Electricity (Supply) Bill, 1921, but no progress was made by the Government with any of the Bills and they were all withdrawn.

Now let us examine what has been done, since the Act of 1919 came into effect, by the Electricity Commissioners whose duty under the Act is to promote, regulate and supervise the supply of electricity in this country under the general directions of the Minister of Transport. The history of the activities of the Commissioners up to 31st March, 1921, is to be found in their first Annual Report which was recently published. So far as I can gather, the efforts of the Commissioners have been to a large extent devoted to provisionally determining Electricity Districts and holding local Inquiries, (*a*) to adjust the boundaries of those Districts and (*b*) to consider schemes for improving the existing organization for the supply of electricity in the Districts. I understand that at these Inquiries the Commissioners have invariably expected, and indeed have in Form El. C. 30 issued by them requested, electricity supply undertakers to submit schemes for compulsorily setting up Joint Electricity Authorities on the assumption that such Authorities will possess the powers, particularly as regards raising capital, to be conferred on the authorities by an Act along the lines of the ill-fated Bills of 1920 and 1921. It seems to me that, for the Commissioners so to anticipate legislation, is an entirely unwarrantable assumption on their part, which can only be based on a belief that a Government Department is superior to Parliament.

I am informed that eight local Inquiries have been held at which many and varied schemes have been exhaustively considered, and it is almost unnecessary for me to state that enormous labour and very large expenditure of money have been borne by electricity supply undertakers, both company and municipal, in preparing for and attending the Inquiries. My view is that these very troublesome and costly Inquiries, the real object of which is to give the Commissioners an opportunity to press electricity supply undertakers to set up Joint Electricity Authorities, should be stopped forthwith.

These Joint Electricity Authorities are not wanted by many company and municipal undertakers, who recognize that it is futile even to attempt to set up these Authorities to carry out the hastily conceived notions of the Minister of Transport originally incorporated in the Bill of 1919. The general view of electricity supply undertakers throughout the country appears to be that the best results are more likely to be obtained by voluntary co-operation amongst authorized undertakers than by setting up a new body like a Joint Electricity Authority. These views have been significantly put before the Commissioners at the last three local Inquiries which they have held.

At an Inquiry held at Birmingham in November, 1921, a corporation and a power company submitted a *voluntary* scheme to set up an Advisory Committee instead of a Joint Electricity Authority for the South-West Midlands Electricity District, and this scheme is under consideration by the Commissioners. The scheme is, in my view, an excellent example of the voluntary co-operation which can be obtained between a corporation and a power company.

The next Inquiry was held by the Commissioners last month at Manchester to consider a scheme for the South-East Lancashire Electricity District. Here, a Joint Electricity Authority would not be accepted by the undertakers in the District, and a Joint Advisory Board on a *voluntary* basis was proposed to the Commissioners. A suggestion was made by the Commissioners that the scheme should be compulsory, but this was not agreed to; indeed, I understand it was definitely refused by the parties to the scheme.

The last Inquiry held by the Commissioners was at Barrow-in-Furness this month in regard to the North Lancashire and South Cumberland Electricity District. The scheme originally submitted to the Commissioners proposed to set up a Joint Electricity Authority for the District, but at the Inquiry the largest corporation

and other authorized undertakers in the District withdrew from the scheme.

So long as the indeterminate conditions above described prevail, so long will it remain difficult for real constructive development to take place. What electricity supply undertakers desire to-day is security and freedom. They must be assured that there will be no further harmful legislation.

In conclusion, the effect of post-war legislation has, in my opinion, produced under pressure a lesser volume of amalgamation between authorized undertakers than would have automatically emerged by normal development. It has also produced fewer benefits than progress along the lines of freedom, has retarded during the first two years after the war (the vital period for the reconstruction of our industries) the expansion of many electricity undertakings, and has contributed to trade depression owing to the absence of orders for plant, machinery, etc., which would have been placed if no new legislation had been introduced.

SIR CHARLES BRIGHT, F.R.S.E.

Early Submarine Telegraphy.

I would first of all say that this commemoration comes about through telegraphy being the basis of our Institution's forerunner—the Society of Telegraph Engineers and Electricians. My discourse is concerned with early submarine telegraphy.

A Spaniard named Salva suggested the feasibility of submarine telegraphy as far back as the year 1795, whilst in 1811 Sommering and Schilling conducted a series of experiments, in which a soluble material, said to have been indiarubber, was first used for insulating the wire.

In 1840, Prof. (afterwards Sir Charles) Wheatstone explained to a Committee of the House of Commons the methods by which he thought it possible to establish telegraphic communication between Dover and Calais. Then in 1842, Prof. Samuel Finley Breese Morse, the well-known American inventor of the telegraph apparatus bearing his name, laid down across New York Harbour an insulated copper wire through which he transmitted electric currents. Hemp soaked in tar and pitch, surrounded with a layer of indiarubber, constituted the insulation. Morse was a great letter-writer, and records of his early work are based on his own statements at a time when he noted in his diary: "I am crushed for want of means, my hat is hoary with age, and my stockings all want to see my mother."

Effective submarine telegraphy, however, owed its birth to the introduction of gutta-percha for insulating purposes early in 1847 by the late Dr. Werner Siemens, elder brother to the late Sir William Siemens, the first President of our Society in 1872, who must also share considerable credit in this as in most other early electrical problems. Michael Faraday about the same time independently pointed to the insulating properties of gutta-percha.

On the 10th January, 1849, the late Mr. Charles Vincent Walker, electrician to the South-Eastern Railway and one of our original members, laid a gutta-percha covered conductor, 2 miles long, in the English Channel. The wire was coiled on a drum on board the laying vessel, from which it was paid out as the vessel progressed. Starting from the beach at Folkestone, the line was joined up to an aerial wire, 83 miles in length, along the South-Eastern Railway, and Mr. Walker on board the "Princess Clementine" succeeded in exchanging telegrams with London.

Previously, that is to say on 16th June, 1845, the brothers Jacob and John Watkins Brett (bric-à-brac shopkeepers) had registered a company for the purpose of telegraphic communication between this country and France, and on 23rd July of that year they applied to Sir Robert Peel, Prime Minister and First Lord of the Treasury. They were referred to the Admiralty, Foreign Office, etc., and gradually became involved in a departmental correspondence and passed backwards and forwards from one Government office to another. This was but a repetition of the experiences of the late Sir Francis Ronalds who, when bringing his early telegraph to the notice of the Admiralty, was informed that "there is no need for electric telegraphy of any kind in our country." I may here mention that it was Ronalds who left us his library of some 6 000 books. In 1849, after considerable correspondence with both Governments concerned, a concession was obtained by the Bretts for the laying of a cable between Dover and Calais. Twenty-five nautical miles of No. 14 copper wire, covered with $\frac{1}{2}$-inch thickness of gutta-percha, were then manufactured, the electrician's tongue being the only test applied to some of the lengths. The shore ends for about 2 miles from each terminus consisted of a No. 16 B.W.G. conductor covered with cotton soaked in indiarubber solution, the whole being encased in a very thick lead tube. The rest of the line was composed of the gutta-percha insulated wire above described. A number of 30-lb. leaden weights were fastened to the line at 100-yard intervals, the laying vessel—a small Thames tug—having to be stopped every time one was put on. The laying of the line from a huge reel on deck was successfully effected by the late Mr. Charlton Wollaston on 28th August, 1850, but it only lived to speak a few more or less incoherent words—one being a short complimentary communication to Louis Napoleon Bonaparte, shortly afterwards Emperor of the French.

The signalling apparatus consisted of a Cooke and Wheatstone needle instrument which was set up in a bathing machine.

Jacob Brett—who later on became an Honorary Member of our Institution—had a document signed by 20 Frenchmen, who declared that they had seen the electric telegraph working between France and England. The signals were somewhat incoherent, the operators at each end blaming those at the other, and tauntingly suggested that the excitement, or something else, must have gone to their heads. The glory of this telegraph was, unfortunately, short lived, for after the first evening it maintained an obstinate reserve, and

never spoke again. An attempt was then made to raise the wire; but, owing to the leaden weights that had been attached in order that it might be successfully sunk, all efforts were in vain. A considerable length was, however, brought up by a fisherman in his trawl, who carried it off to Boulogne in triumph, as "a piece of rare seaweed with a pith of gold!"

This enterprise excited little attention at the time. It was, in fact, regarded as a "mad freak" and even as a "gigantic swindle." When accomplished, *The Times* remarked, in the words of Shakespeare, "the jest of yesterday has become the fact of to-day"; but a few hours later it might with equal truth have been said that "the fact of yesterday has become the jest of to-day"! The feasibility of laying such a line and of transmitting electric signals across the Channel had now, indeed, been proved. The signals obtained had, moreover, the effect of eradicating the then very prevalent belief that, even if the line were successfully submerged, the current would become dissipated in the water. It now remained to find a satisfactory method of protecting the insulated conductor from injury during and after laying.

On 19th December, 1850, a new concession was granted to Jacob Brett by the French Government, and on the strength of this the Submarine Telegraph Company (since absorbed by H.M. Post Office) was formed. But £300 was all that the public would subscribe, because it had been proved that submarine telegraphy was an impossibility! Yet these early pioneers, with that peculiar obstinacy that characterizes inventors, actually went on believing in their own ideas.

Thomas Russell Crampton, a leading railway engineer of that time, came to the rescue with £7 500 of his own and a similar amount from his friends. Then Mr. Küper, a colliery engineer, came along and said: "Why not protect your gutta-percha covering by an iron sheathing?" The cable with its pit-rope like sheathing of to-day was duly made, and on the 25th September, 1851, a procession with a man-of-war to lead the way, started from the South Foreland to the shores of France. All went well until they were in sight of the opposite coast, when the cable gave out. Another mile was ordered, manufactured, and laid; and on the 13th November actual messages were exchanged on a more or less practical scale.

The Bretts then applied to the Government for a monopoly to connect England and Ireland electrically. This time they were not so fortunate; for, on 10th September, the Admiralty wrote that "they had watched with interest the progress of the experiments, but had no power to grant a right." On the 18th the "Foreign Office is directed by Viscount Palmerston, to congratulate you upon the success of your experiment, and to state that the matter does not relate to the business of his Lordship's Department." On the same day the Admiralty again wrote, "that whatever privileges can be granted, can proceed only from the Treasury." The next day, the Treasury "acquaint you that it is not in the power of the Lords Commissioners of Her Majesty's Treasury." They got the same answer on 28th September. On 18th October, 1850, they received the following letter from the Treasury:—

"Although sensible of your perseverance in bringing the submarine telegraph about, and in view of the great public benefit likely to arise in connection, but it is not in their Lordships' power, etc."

Cables were then laid between England and Ireland; and although the first two efforts were failures—partly due to faulty design—in 1853 my father, the late Sir Charles Tilston Bright, another Past President of the Institution, successfully connected the two islands—this early piece of cable work being performed at the age of 21.

Then followed a number of lines laid across the English Channel, in the Mediterranean, and elsewhere. Most of these were attended by failure, due to breakage of the cable, or to it being paid out with so much slack (for want of satisfactory controlling gear) that it reposed in festoons at the bottom of the sea.

We now come to the period when a much more difficult problem was dealt with—the spanning of the Atlantic Ocean by laying and speaking through a cable 2 000 miles in length, the depth being upwards of 3 miles. Many eminent scientists had said it would be impossible to deposit the line at so great a depth; and that, even if laid, it would be a mathematical impossibility to transmit electrical signals through such a length. The Atlantic cable scheme was, indeed, considered at this time (1857) another wild scheme of people that were to be pitied, but its realization later was aptly described as "the great feat of the century." We have had, of course, many "stories" of the Atlantic cable, several of which may be said to be stories in every sense—resulting apparently from dreams emanating from outside this country. The actual facts, however, are still available in the form of official documents and records. Some of these I have already had pleasure in presenting to our Library.

The projectors of this undertaking, who were the subject of so much pity, were John Watkins Brett (already alluded to), the prospective Managing Director, Cyrus West Field, a wealthy American business man of enormous energy, who had with considerable foresight bought the sole landing rights for a cable at Newfoundland, and my father, who also became the engineer.

There were evidently some spirits who believed in the enterprise—or in those at the back of it—for the Atlantic Telegraph Company was formed within a few days, almost the entire capital being raised in our country by the public issue of 350 shares of £1 000 each.

The proposed route was surveyed in what we should now consider to be a somewhat "sketchy" fashion; for whereas, in the present day, we sound at intervals of about 10 miles, at that time soundings every 100 miles were considered to be abundant.

The manufacture of the line was duly proceeded with—partly at the Greenwich works of Messrs. Glass, Elliot and Co. (afterwards the Telegraph Construction and Maintenance Company), and partly at Messrs. R. S. Newall and Co.'s factory near Liverpool. The iron sheathing was composed of several strands of fine wire.

The Governments of the countries concerned en-

couraged the scheme to the extent of lending certain vessels for laying the cable, as they had done previously for the survey. The main contribution from the United States was the "Niagara"—a splendid example of the frigates of that time; a smaller vessel was also provided by each Government to land the ends, pilot the way, and act as consorts generally.

Mishaps soon occurred; for it was only 4 miles that had been paid out when the cable broke. Another start was made; but, after 226 miles had been laid, it again broke—this time, however, at a depth of 2 miles. So ended the first attempt to connect America with Europe electrically. Morse, who was on board in an honorary capacity, recorded the circumstances as follows:—"The cable parted just before daybreak. The machinery having stopped, all hands rushed on deck and gathered in mournful groups; their tones were sad, their voices low, as if a death had occurred on board."

The next year (1858) more cable was made, and a second expedition started. The two vessels were this time to meet in mid-ocean and make a joint, and then sail in opposite directions, laying the cable towards their respective shores. This they did, but the joint broke. They made a second, and again it broke. They made a third, and then one ship sailed towards Ireland and the other towards America.

On her way, H.M.S. "Agamemnon" encountered a whale, and though the ponderous monster made commendable attempts to carry off the cable, these attempts were attended with no evil result. The "Niagara," however, had not gone far before another break occurred which ended in the loss of 500 miles of cable. Sufficient yet remained on board for a third trial.

Meanwhile, however, both ships had run out of stores; and it was therefore necessary to put into Queenstown. On the way, a terrific storm was encountered, and the "Agamemnon" nearly "turned turtle," whilst the cable and the coals got terribly mixed up. The whole proceedings were graphically described by *The Times* correspondent who accompanied the expedition.

Matters were in the end righted; and after stores had been procured, the telegraph fleet once more met in mid-ocean to make the splice, and again set forth on their respective work. The first expedition created considerable excitement, but when it came to the second and third, everyone—except the shareholders—merely pitied those that were continuing such a futile errand. The pity was, however, now beginning to be misplaced; for this time the entire line was laid successfully.

Though having comparatively little to do with the actual work, our American cousins were more demonstrative on the subject, and wild excitement prevailed on the landing of the end at Newfoundland station. But even *The Times* remarked: "Since the discovery of Columbus nothing has been done in any degree comparable to the vast enlargement which has thus been given to the sphere of human activity."

It was on the 5th August, 1858, that England spoke for the first time electrically with America.

The cable never worked very satisfactorily from the outset, for the message from the United States President to Queen Victoria occupied over 30 hours in transmission, though only containing 150 words. Moreover, the utmost speed achieved was some 6 words a minute.

Though doing useful work for over 2 months and carrying 732 messages, the line was gasping under its efforts throughout, and gradually reached the sinking stage. It was suffering—and ultimately succumbed—from the effects of mistaken electrical views, in which even the great Faraday shared. The line was, indeed, an electrical failure, though a complete engineering success. It had been proved that such a length of cable could be laid in really deep water; and, though various mishaps had occurred before final engineering success was achieved, these were only due to unavoidable accident on the one hand, and lack of perfection in manufacture on the other, such as could be improved on by the experience gained. As engineer-in-chief, my father was knighted when but 26 years old.

From the next cable, however, that laid by the Government in the Red Sea in 1859—nothing useful was learned. The sections failed one after the other, and it is doubtful whether a message was ever sent through the whole of the cable; but it is certain that the British public continued to pay, until the year 1908, £36 000 per annum for the privilege of having put some copper wire, gutta-percha, and iron sheathing at the bottom of the Red Sea.

There were several other cables laid soon after—from Malta to Alexandria, to India and elsewhere—and these proved a complete success; indeed, the line to India via the Persian Gulf is usually regarded as the pioneer in the matter of full and satisfactory arrangements for testing previous to, and during, laying.

It was not until 1865 that the question of re-spanning the Atlantic took active shape. My father with his partner the late Mr. Latimer Clark—a Past President of this Institution—had, in the interval, persuaded the financiers that a larger and more costly insulated conductor was essential. Moreover, the electricians were also better advised in regard to the generating power and apparatus for signalling purposes. Indeed, Professor William Thomson (afterwards Lord Kelvin)—three times President of the Institution, i.e. in 1874, in 1889 and again in 1907—had not only introduced his mirror speaking instrument, but became the electrician in place of Dr. Wildman Whitehouse. The Thomson mirror apparatus proved the turning point, commercially speaking, in ocean telegraphy—both as regards signalling and testing—though since superseded by the Thomson "recorder" for the former purpose.

Then, again, at this stage in the history of submarine telegraphy, the improvements in manufacture, due to experience, were altogether encouraging, and the late Mr. Willoughby Smith (Past President of this Institution) as well as Mr. Cromwell Fleetwood Varley had done much towards developing the electrical side of submarine telegraphy.

The larger-sized core meant a larger-sized cable, and this could not have been got into any other vessel

than the "Great Eastern," which, as it chanced, happened to be available. The paying out and picking up machinery—fitted with Appold brakes—was of a high order, being largely due to the mechanical skill of the late Mr. Henry Clifford.

In the 1865 cable several faults occurred, and once, while attempting to haul it back to repair a fault, the cable snapped, after 1 186 miles had been laid. For 9 days they made strenuous efforts to pick it up; but though they grappled it many times, the rope broke, and thus the 1865 cable had to be abandoned. A new cable like that of 1865 was then made by the Telegraph Construction Company.

The new cable, after a few further misfortunes, was eventually laid. From an engineering standpoint, however, this was really work that had already been effected 8 years previously, with about the same number of misfortunes, though with no applicable experience to go upon. The work to come—that of recovering the 1865 cable—was, indeed, the matter of the moment.

For 13 days they alternately hooked and lost the cable. Once they brought it to the surface, but it slipped away from them like a great eel. On lowering the grapnel, however, for the thirtieth time they succeeded—thanks mainly to Mr. (afterwards Sir Samuel) Canning, the chief engineer to the contractors; and, thus, two good cables were laid between England and America.

Numerous other cables to the East and Far East, as well as across the Atlantic, followed; and these, thanks to the commercial foresight and enterprise of men like the late Sir John Pender, originally a great Manchester cotton spinner, have all proved highly profitable.

The idea of a trans-Pacific cable (running into 4-mile depths) used to be derided just as the Atlantic cable was. Ultimately, however, two lines were laid across the Pacific and have proved entirely successful.

By far the larger proportion of the cables at the sea bottom have been made and laid by British hands, though the present state of things in this respect seems unlikely to prevail for long.

We cherish the memory of many great names associated with submarine telegraphy, but the greatest of all may be seen perpetuated on the walls of our Lecture Hall—William Thomson, Baron Kelvin of Largs—who, perhaps on account of his real greatness, was also throughout life so generous regarding the work of others and so simple-minded and good in every respect.

The pioneering of submarine telegraphy was very thoroughly thrashed out in connection with the proposed "International Memorial to the Inception and Extension of Submarine Telegraphy" in the year 1896. It was then ultimately agreed that Submarine Telegraphy only became a matter of commercial development and profit by the efforts of engineers and electricians.

In addition to the various meetings of the executive committee, the subject was exhaustively discussed in the Press. Attention may be especially called to *The Times* of 12th, 13th and 15th October, and 28th November, as well as to the *Morning Post* of 14th October, also of that year (1896).

Owing to his supreme position, the late Lord Kelvin may, perhaps, be quoted as an authority above all others who worked in this field. He expressed himself very definitely on the subject of where credit was in the main due, not only at the meeting of the Committee just referred to, but also in the course of his I.E.E. Presidential Address of 1889, when he expressed himself thus regarding the pioneering of ocean telegraphy:—

"To Sir Charles Bright's vigour, earnestness and enthusiasm was due the successful laying of the first Atlantic cable. We must always feel deeply indebted to our late colleague as the pioneer of that great work, when other engineers would not look at it, and thought it absolutely impracticable."

Though at that time rather a youthful member of the executive committee in connection with the aforesaid proposed International Memorial, I had the satisfaction in the end of carrying my amendment unanimously. It was seconded by the late Sir John Wolfe-Barry and warmly supported by Lord Kelvin and Sir John Lamb, the then Secretary of the Post Office.

Some years ago I contributed to the Institution's Library several volumes of newspaper cuttings, all relating to the early days of telegraphy, land and submarine, and in these much information on early cable work may be found.

In this connection attention may also be called to Haydn's "Dictionary of Dates" where, under "Electricity," all the main features in the pioneering of submarine telegraphy are set forth in their chronological order.

These additional matters are mentioned only because a doubt seems to creep up occasionally as to where credit was mainly due for the early pioneering of ocean telegraphy.

Having been asked to deal, in this "Discourse," with "Early Submarine Telegraphy," I have naturally confined myself to that subject, and have, therefore refrained from giving any personal reminiscences of a later period.

MR. R. A. CHATTOCK.

I think my earliest experience in connection with electric lighting was when I was going through the engineering course at University College, London. It was about the year 1882 that Prof. J. A. Fleming commenced his course of lectures in Electrical Engineering at the College, and I remember that he showed us some of the first Edison incandescent lamps that had come from America. We were very interested in the blackening of the bulbs that had occurred and in his explanation of the reason for this, that it was due to the bombardment of the glass by carbon particles from the filament. As evidence of this, he pointed out the clear line down one side of the bulb which was screened by one leg of the filament. We do not seem to have

yet eliminated this drawback to the use of incandescent lamps, although the steadier pressures that are now available have got over the difficulty to some extent. I remember that Prof. Fleming took us down to a building close to Ludgate-circus to show us the first Edison dynamo that had been installed in this country—a weird bipolar machine with long, thin magnets wrapped with cotton-covered wire.

It was not until six or seven years after this that I became personally connected with the industrial side of electric lighting, by joining the staff of the Metropolitan Electric Supply Company, then almost at the commencement of its existence. The supply station in which I had my first experience of shift work was situated beneath the roadway in front of Whitehall-court, and it contained three 100-kW Willans-Crompton sets, with three marine-type dry-back boilers and a storage battery. I remember that supply was given, amongst other places, to the Victoria Hotel and the Garrick Theatre, and it was the duty of the shift engineer occasionally to visit these large consumers and see that all was in order. The visits to the latter were of course always undertaken during the performance, and formed a welcome interlude to the somewhat onerous duties of a shift engineer in those days.

The Metropolitan Company, it will be remembered, broke away from direct-current supply and instituted single-phase alternating current in their stations at Sardinia-street, Rathbone-place and Manchester-square, the station at Amberley-road being erected subsequently. It was at this time that the battle of the currents became rather acute. The Westminster Supply Corporation went in for direct current and the junior engineers of this Company and the Metropolitan Company had much wordy warfare as to which was the best system. I am not sure that this knotty question has ever been finally settled, although things have settled down into accepted practice, more as a result of expediency than justification. At that time, some consumers would not have alternating current at any price, and I recollect that in one alternating-current station special arrangements had to be made to supply one large theatre with direct current. The proper regulation of this was, of course, not easy to carry out, and eventually a storage battery was put in to get over the trouble. A representative of the theatre, who called periodically to complain of the variation in the lights, was introduced by the shift engineer to this battery, and told that he "would soon be all right, as we had put a filter in to filter the current before it reached him, and it would not come through so lumpy in the future."

It is interesting to observe that a similar battle is now going on called "the battle of the frequencies," and it is to be anticipated that the result will be very similar.

In those pioneering days, the life of the junior engineer was always full of absorbing interest, as well as new and often unrehearsed experiences. Switches mounted on wood, which had a habit of warping, were hardly conducive to cool running, and I remember on more than one occasion seeing the wooden base of a switch beginning to smoke, due to the heating of the switch blocks. The use of rubber-covered cables at the backs of the switchboards was another fruitful source of trouble. The hot connection on the board soon caused the rubber to melt, and fires, which on one or two occasions were disastrous in their consequences, were occasionally started in this way.

The life of a shift engineer at the present time must be a really humdrum experience compared with what it used to be in the old pioneering days, although perhaps the public are to be congratulated on this, as evidence of greater reliability of supply.

It would be possible to go on for a long time describing the troubles of the early days, but I think I have said enough to indicate what a vast difference there is between those days and the present time.

MR. H. J. DOWSING.

Electric heating may be said to have begun with the practical demonstrations made at the Crystal Palace Exhibition of 1892. At that time I was in charge of the machinery exhibit of Messrs. Crompton & Co., with whom I had been engaged since 1882, and, having recently become interested in the subject of electric heating, I arranged a joint exhibit of electric heating appliances with that firm and the General Electric Co. in a room obtained for the purpose from the Crystal Palace Company. I gave practical demonstrations and lectured three times daily to enthusiastic audiences. At that time the only appliances we had of a practical character were electric kettles, frying pans, grillers, saucepans, and electric radiators. I employed a cook who used the appliances before the audience in grilling steaks, boiling potatoes, frying pancakes and many other operations, and we handed round to the audience cups of tea which had been made with water boiled in the electric kettles before their eyes. Frequently members of the audience would ask to be allowed to look under the table, and they acknowledged that they expected to find a gas cooker of some description, as they could not conceive the possibility of electricity supplying the heat necessary for the cooking they had seen carried out. The daily Press throughout the country noticed the cooking demonstrations and called attention to the great possibilities in the use of electricity for domestic purposes, and one of the comic illustrated papers published a fancy sketch showing the chops that had been cooked by electricity, jumping about on the plates and giving the people shocks! Altogether the introduction of electric cooking caused great interest. Incidentally the gas companies took alarm and commenced an extensive programme of gas cooking.

The first public dinner cooked by electricity was one that I organized for the City of London Electric Lighting Co. at Cannon-street Hotel, 15th June, 1894. Six large ovens were employed with hot-plates, etc., and we provided for 120 guests, using 60 kWh.

The cookers were made by enamelling resistance wires to the bottoms of the utensils, the current

passing through these wires producing the heat necessary for the cooking operations. Cooking and heating appliances were made on this principle for some years, and appliances made at that time which were not required to produce high temperatures are still in use. The difficulty, however, was to obtain wire with the same coefficient of expansion as the enamel, or vice versa. Bare resistance wires enclosed in cases or fixed on porcelain or enamel supports were used as they are at the present time, but they were not durable, the wire becoming oxidized when run to a red heat. It must be remembered, too, that electricity was charged for at something like a shilling a unit and no special rates were then available for current supplied for electric heating.

By the introduction of high-resistance, non-oxidizable wires such as "Nichrome," heating elements made with bare electric wires have become possible, and led to vast extensions in the use of electricity for heating purposes. Electric heating was used largely in connection with the late war, and one of the most interesting uses was the making of airmen's electrically heated clothing which made it possible for aviators to ascend to great heights in spite of the intense cold of those regions.

About 1895 I began investigating the radiant heat produced from electric heating lamps, and after many failures succeeded in producing special heating lamps taking from 250 or 500 watts and from which the heat was given off by radiation. I took out various patents for electric radiators in which the heating elements comprised these lamps. They were true radiators, as practically all the heat was projected in the form of luminous heat rays. The great heat caused many lamps to fail owing to the glass melting. The lamps appeared to work satisfactorily in the open air, but I found that if a reflector was placed behind them, the glass on the reflector side immediately softened and gave way. To overcome the melting of the glass I devised a V-shaped reflector, and the back rays were thus reflected away from the lamp itself. Shortly afterwards I had the lamps made in an elongated form and used a V-shaped reflector with the apex of the reflector running parallel to the lamps which were placed vertically in the radiator. The V-shaped reflector also formed a flue when heated, up which warm air was drawn and dispersed in the room.

Many thousands of these luminous heat radiators were made and they are an everyday article of commerce at the present time. For ship use they were found to be exceptionally good, and for warming cold parts of rooms, passages, bedrooms and local heating they were very successful. The efficiency is about 98 per cent.

While engaged in developing this system of heating, my attention was drawn, by a very eminent member of the medical profession, to a particular use where heat rays such as I used could be employed in medical practice. Many experiments were made, covering two or more years, in the application of radiant heat for the treatment of rheumatic, gouty and neuralgic cases, and the success was so great that I patented various appliances and established medical institutions where medical men could send their patients for treatment. Over 100 war hospitals were equipped with this apparatus, and 130 other establishments (nursing homes, hospitals, etc.) arranged to give the treatment in various parts of the country. This system of treatment is entirely in the hands of the medical profession and is extending in various directions. It is gratifying to know that thousands of wounded men were benefited by the application of radiant heat.

MR. HENRY EDMUNDS.

It is very difficult to condense into a short space much that I feel would be of considerable interest to the younger members of the Institution of Electrical Engineers, and I naturally hesitate to dwell too much upon my own personal experiences.

The first meeting of the Institution that I attended was in February, 1878. I had just returned from my first visit to the United States, where I went in 1877. As I arrived in New York, Sir William Preece was just leaving, he having been in America for several months investigating the newly invented "telephone." He brought to England the earliest official information regarding the invention of Mr. Graham Bell, and in the autumn of 1877 he demonstrated and described the telephone to the British Association at Plymouth. Nevertheless there were many who doubted whether sounds could ever be conveyed to a distance by any electrical mechanism. To convince the sceptics he arranged with the London & South-Western Railway Company that one of their telegraph lines should be connected at one end into a room at Southampton, and led at the other end into the lecture theatre of the Royal Institution: the idea being to station a bugler at Southampton who would play his instrument at a stated time before the transmitter there; and the music would then be audible in London through the receiver of a telephone, thus demonstrating the possibility of transmitting sound electrically over long distances.

Sir William Preece's lecture was delivered one evening in March, 1878. There was a large and distinguished audience, who listened with breathless attention. Sir William told them that by listening at a mouthpiece in that hall it would be possible to hear the notes of a bugle played 80 miles away. Looking hard at Lord Tennyson Sir William said: "As the instrument is too feeble for you all to hear it, I will ask Mr. Alfred Tennyson kindly to step up to this platform, and tell the audience what he can distinguish." Amid a hushed silence, the poet listened for a few minutes at the receiver; and then remarked gruffly: "I hear nothing." Sir William started, caught up the telephone, and held it in a listening attitude, and said: "I can hear 'The Campbells are Coming.'" He then glanced round the hall and proceeded with his lecture and the exhibition of the other apparatus.

A few days afterwards I met Sir William Preece, who said to me: "Do you know, Edmunds, we had a most unlucky hitch the other night at the Royal

Institution!" "How so? Everything went splendidly!" I replied "The bugler!" he rejoined. "The bugler mistook the date; and did not turn up until the next evening! No wonder Tennyson could hear nothing!"

I had gone to America at the suggestion of Mr. Richard Werdermann, whom I had met at the demonstration of the Jablochkoff electric light at the East India Dock on the 15th June, 1877. This was for that period an epoch-making advance. Although single arc-lighting had been effected for some time, from batteries or magnetos, it really meant that each magneto could only operate one arc. Jablochkoff had succeeded in the so-called subdividing of the electric light; and for the first time the public had an opportunity of witnessing a number of lamps run in series from one magneto-electric machine. I was introduced to Mr. Jablochkoff by Mr. Robert Applegarth. There was a round of applause when the vast, dim dock shed was suddenly lit up by a number of brilliant points of light. Mr. Jablochkoff also exhibited an induction coil, the forerunner of the transformer; and a semi-arc heating a kaolin strip to incandescence: a method somewhat like that better known later under the name of the Nernst lamp. Mr. Richard Werdermann introduced himself to me; and as a result of the conversation I proceeded to the United States. On arrival there I found great progress had been made in electric arc illumination. I met Mr. William Wallace who, in conjunction with Prof. Farmer of Newport, had just developed the Farmer–Wallace arc lamp, which was not a specially made "candle" like that of Jablochkoff; but a true arc lamp that could be run in series. I brought over a Farmer–Wallace dynamo, and a number of the lamps, and installed them at Liverpool–street Station in 1878, this being the first railway station in the world to be illuminated by arcs in series, and the first public example in this country of lighting by arc lamps in series. Shortly afterwards I was again in America, and was introduced to Mr. Charles F. Brush by the Wallaces, and saw his inventions. Mr. Brush was the first to present a practicable dynamo with arc lamp in series, using carbons, and regulated by mechanism like the arc lamps of to-day. The Anglo-American Brush Electric Light Company was formed; and electric illumination took the position in this country from which it has never receded.

On the 24th November, 1880, Mr. Joseph W. Swan read a paper before this Institution upon a new method for the subdivision of the electric light. This time he did not employ arcs, but an entirely new method, namely, the heating of a spiral of carbon "wire" in an exhausted glass tube or bulb. I became associated with Mr. Swan in 1881. The first practical application of the Swan lamp in London was in the dining-room of Sir William Spottiswoode in March of that year. At that dinner was Capt. J. A. Fisher, better known afterwards as Admiral Lord Fisher of Kedlestone. Capt. Fisher was so interested that he asked whether it would be possible to have the new lamps fitted in his ship the "Inflexible." Accordingly I was sent to Portsmouth where I met Capt. Fisher, who took me over the "Inflexible" and told me he had arranged for a demonstration in a shed in the dockyard; he warned me to be careful how I answered any of the questions of the Admiral, who was of the stern old school, and prejudiced against all new-fangled notions. The Admiral appeared resplendent in gold lace, and surrounded by such a bevy of ladies that I was strongly reminded of the character in H.M.S. "Pinafore" "with his sisters, and his cousins, and his aunts." The great man immediately asked if I had seen the "Inflexible." I replied that I had; and had been in the powder magazine. "What would happen to these little glass bubbles in the event of a broadside?" I replied that I did not think it would affect them. "How do you know? You've never been in a ship during a broadside!" A tray was brought with a layer of guncotton upon it, sprinkled with gunpowder; and the Admiral asked if I was prepared to break one of the lamps over this tray. I replied that I could do so quite safely. I smashed a lamp with a cold chisel. The assembled company saw the light extinguished, and a few pieces of glass fall on the tray. There was no flash, and the gunpowder and guncotton were unaffected. The Admiral gazed at the tray for a few seconds. Then he turned and said to Captain Fisher: "We'll have this light on the 'Inflexible.'" And that was the introduction of the incandescent electric light into the British Navy.

Years afterwards, in 1919, I sent Lord Fisher a note on this occurrence, and he replied in his own handwriting on the 27th October, 1919, saying:—

"Dear Mr. Edmunds—I'm exceedingly obliged. I remember it all. Specially your very lucid exposition. I'll have you in my second book as a Pioneer! Yours, FISHER."

Lord Fisher was as good as his word; and he has a reference to my work in his last book, published a short time before his lamented death.

The lighting of the "Inflexible" was immediately followed by the installation of the Inman steamship "City of Richmond," the first large merchant ship to be illuminated in that way, followed by the s.s. "Servia," of the Cunard line: all in 1881.

While thus chiefly employed in electrical engineering I was keeping in touch with other scientific developments. In 1877 Mr. Thomas A. Edison visited Mr. William Wallace to see a machine Wallace called a "Telemacon" intended for the transmission of power electrically. I was introduced to Mr. Edison, who asked me to come and see his laboratory at Menlo Park. On opening the door, we saw Mr. Edison, who held up one hand dramatically, and turned a small brass cylinder with the other. To my surprise I heard the words "Mary had a little lamb!" articulated by this cylinder. It was the first phonograph; and I was just in time to hear the primary reproduction of recorded human speech. On my return to England I gave details to Mr. Augustus Stroh, who constructed an instrument which was successfully used by Sir William Preece in describing the new invention at the Royal Institution, and the Institution of Electrical Engineers in February, 1878. In Paris in 1881 I lighted the Grand Opera House, and the first French battleship at Brest; also the British section of the first Electrical Exposition at Paris.

I can thus claim to have been influential in introducing into Europe not only the first practical apparatus for arc-lighting, but the first example of speech-recording machinery which has since received such remarkable development. In addition to this I may also claim to have been an active pioneer in the introduction of incandescent electric lighting, so familiar to us all to-day.

SIR KEITH ELPHINSTONE, K.B.E.

The electrical instrument-making business of Elliott Brothers is among a very small number of electrical businesses which were carried on in the year 1872 and are still being carried on to-day, and some notes on the doings of this business may prove of interest.

As a matter of fact, the Elliott Brothers of 1853 carried on the business of their father William Elliott, who started as an instrument-maker in High Holborn in the year 1800. In an old order book of the year 1816 the first order which can be called an electric one, is entered on 21st October :

> " Dr. Gladstone of Greenwich.
>
> To make two stands for electric jarrs, $3\frac{7}{8}$ diameter —2s. 6d. each."

Government orders extend back many years, and the Lords of the Admiralty ordered in March 1840 an example of " Mr. Colladon's apparatus to measure depths by pressure of the sea "—no details remain.

In August 1849, an order was entered :

> " Repairing batteries at the House of Commons ; material used 10 lb. zinc, 2 ounces of copper ; time $30\frac{1}{2}$ hours."

It would be interesting to know what the batteries were used for at that date.

An order—16th March, 1840—was entered for :

> " Battery and squibs to fire and discharge cannon " ;

but unfortunately nothing in the way of description remains.

The firm's descriptive catalogue, date 1856, of Magnetic, Electromagnetic, Electro-dynamic and Magneto Electric Inductive Instruments and Apparatus, contains a quaint description of a motor.

" No. 100. Electromagnetic motive model consisting of vertical permanent steel magnets and horizontal soft iron electromagnets with contrivances on the main spindle for reversing the direction of the current and thus to produce rotatory motion by the electric and magnetic forces."

A large number of pieces of special apparatus were made for Michael Faraday about this time ; unfortunately, few records remain, as the fall of a wall during the demolition of buildings in the Strand to make room for Charing Cross station destroyed many books and papers.

The electrical instrument business grew rapidly in the years 1864 to 1872, the British Association Committee on Electrical Standards calling for many pieces of apparatus, and the submarine telegraph business demanding galvanometers, resistance boxes and keys of all sorts. Testing instruments for laboratories followed and kept the electrical part of the firm busy for many years, extensions being required in order to cope with the demands for measuring instruments for electric lighting undertakings, and later for tramway enterprise and electric power distribution schemes.

Starting in Holborn in 1800 and moving to the present factory in 1900, the firm decided on the name " Century Works " for their present works at Lewisham.

Manufacturing methods have changed continually, and a cost record of August 1858 may be of interest ; it deals with the first Ruhmkorff coil made by the firm, and it shows that only one man worked on it, being paid £8 5s. for 22 days' work. This is the only wage item in the cost, and it works out at 9d. per hour, which was the remuneration in those days for the best-paid workman in the firm's small shops ; his weekly rate was 42s.

A wage book of 1860 to 1862 shows the average wages paid to a full-rate instrument maker to have been 35s. per week of 55 hours. There were two packers and porters on the wage sheet in those days, who always wore top hats when out of doors to support the dignity of the establishment in the Strand.

As an instance of the changes in conditions as to materials, entries in an old cost record book may be quoted, aluminium sheet being entered at 3s. per ounce, and platinum at 42s. per ounce, the latter in 1894.

As regards testing and measuring instruments, requirements as to accuracy have become, very properly, more and more stringent ; and have now been definitely established by Standard Specifications ; but in the old days before the establishment of the Board of Trade Standard Laboratory and, later, the National Physical Laboratory, there were constant difficulties and discussions, as can well be imagined.

The testing equipment of a modern instrument factory becomes more and more elaborate, and a great deal of scheming out is required to deal economically with the practical tests of electrical apparatus for power measurements of thousands of kilowatts ; and also in naval work to secure practical representations of a target many miles distant viewed from a rolling platform, which also turns from side to side as a ship does at sea.

In dealing with the manufacture of a large number of different small pieces of apparatus, development and progress take place in small steps and no very outstanding or startling inventions appear to stand out, as they do in the heavier branches of electrical work. In thinking over early devices for electrical measurements which one has met with, it is very difficult to separate out any very outstanding features.

As regards measurement of resistances, the methods employed in the early days of telegraphy remain with

us to-day—a Wheatstone bridge and some form of galvanometer. The coils in the early bridges were, however, not very free from variations due to temperature, and that fact covered up a great deal of discrepancy between different examples of apparatus; the improvements in the alloys used for the coils led to greater precision being possible in actual measurements, and probably the greatest step came in the development of manganin alloy, nearly 30 years ago, in Berlin.

As regards measurements of current, the earliest device which occurs to one as a commercial proposition is the Siemens dynamometer. This, provided one did not spill the mercury out of the little cups and got the apparatus well levelled up, enabled a balance to be obtained by turning the torsion head; one then looked up a table supplied by the makers, which told what the current was, and whether it was correct within 5 per cent really did not matter very much, but one knew more about it than one did before.

The Ayrton and Perry ammeters with a permanent magnet and a small pivoted iron armature turned by the action of current through a coil, provided a useful portable form of direct-current measurement; there, again, a card was supplied with the instrument and one could look up what the makers thought was the current corresponding to any deflection.

The introduction by Weston of a well-designed and well-made application of the moving-coil galvanometer was, perhaps, the greatest step in direct-current measurement about 30 years ago.

MR. W. B. ESSON.

Some Early Recollections of Dynamo-Electric Machinery.

To commence at the beginning of my experiences I must go back 40 years. Much current has run through the meters since then, and though I can give some account of the work of the early days, I cannot recreate the atmosphere which existed at a time when we were all young and enthusiastic; when we knew nothing and had everything to learn.

In 1880 the Gramme and Siemens machines were in use for arc lighting, and in this year the first incandescent lamp factory was started on a commercial basis. For about two years Mr. Brush had been working hard in the United States at his lighting system and had achieved such success that his company were allowed in 1881 to test the system on a mile of the New York Broadway at their own expense. By 1882 most of the big railway stations in London as well as the South Kensington Museum and part of the City were being lighted on the Brush system. I had a good deal of experience with Brush plant and, though the lapse of time has somewhat steadied my enthusiasms, I have no hesitation in saying to-day that the inventions of Mr. Brush, which together constituted his system, were amongst the most important in all the domain of electric lighting. His lamp was a marvel of simplicity and ingenuity and he was the first to solve satisfactorily the problem of running arc lamps in series.

Alternators had been constructed for nearly half a century and many powerful machines were in use for lighthouse work. These had permanent magnets, but in the alternators of 1880 the permanent magnets had been superseded by electromagnets and, to the best of my recollection, there were then only two practical designs. The first was the Siemens machine, the armature of which consisted of a circle of coils without iron cores rotating between two circles of magnets facing each other, the adjacent poles in each circle being N and S alternately; the facing poles were also N and S. The second was Gramme's machine, the armature of which consisted of a cylinder of soft iron wire on which coils were wound in groups, and inside which rotated a circle of radial magnets. Both these machines were designed for the purpose of providing multiple circuits, in the case of the Siemens for feeding arc lamps, and in the case of the Gramme for feeding Jablochkoff candles. Apart from the matter of division, there was no advantage in alternating current because the transformer had not yet been invented. Some electricians seemed to be under the impression, however, that for large outputs alternators would generally be used. There must be, they argued, a limit to the size of direct-current machines, but to alternators there was no such limit as they were composed of a large number of similar elements grouped together. Large alternators were, in other words, a number of small alternators combined.

In 1882 the Telegraph Construction and Maintenance Company constructed a colossal alternator to the designs of Mr. J. E. H. Gordon. It was said to be capable of supplying from 5 000 to 7 000 20-c.p. lamps at 140 r.p.m. Apart from the fact that it was an attempt to meet demand on a large scale and that it was built on engineering lines, it was only Pixii's machine designed nearly half a century before, immensely magnified and with electro-magnets substituted for permanent magnets. Now that we have got the right perspective, we can see that, on the electrical side, the machine did not possess any novel features, though this is no disparagement of Gordon's scientific attainments.

In the same year there were heard rumours, with which Sir William Thomson's name was coupled, of a wonderful machine about to appear, which turned out later to be Ferranti's alternator. This alternator was undoubtedly an improvement on the Siemens, for the zigzag copper ribbon gave a stronger and stiffer armature than individual coils connected to a central disc by German-silver side plates. But, given the same intensity of field and the same speed, the weight of copper in the armature required to produce similar effects would have been exactly the same. Ferranti's point was, of course, that the construction of the Siemens machine could not permit of its being driven at his speeds, and there he was quite right. All the mechanical details of this machine were well thought out and it was a sound engineering job.

In the meantime direct-current machines of large output had also been constructed. Edison dynamos, each capable of supplying about 1 200 lamps, were in

1882 installed at Holborn-viaduct station. Like some other machines those had multiple magnets but the ordinary drum winding on the armatures was superseded by copper bars connected at their ends by copper discs, so that here also progress was denoted from the mechanical point of view.

The foregoing will give an idea of the state of design in 1882. Most of the original designs had been of a flimsy character, as witness Gramme's ring on a wooden hub, Perry's coiled wooden ring, Elphinstone and Vincent's papier-mâché drum, Sir William Thomson's copper band wound into teeth on a wooden disc, and so on. These early inventors had apparently no idea of the forces which would have to be dealt with but, as designing was getting into the hands of trained engineers, the mechanical part was being put on a proper basis.

Design on the electrical side was, however, only beginning. In running ring armatures in single horseshoe magnets we had some trouble at first with sparking, owing to the field flux being greater in one half of the ring than the other. This was soon cured, however, by leaving plenty of iron around the polar cavity and by placing the armature a little eccentrically. There were some curious ideas held about magnets in those days. Some writers enjoined us to make them long and some to make them short, so the only way was to find out for ourselves the best proportions. Many views were derived from telegraph practice, but it was only as we ceased to consider matters analogically that we could begin to consider them logically.

From 1884 onwards I was busy carrying out at Messrs. Paterson and Cooper's works experiments to settle points respecting which no data existed, and we collected much valuable information. Amongst other things we investigated the relation between the strength of field and the drop in volts as the current increased in self-excited and shunt dynamos and alternators; we determined the best ratio of magnet-core area to armature-core area; we showed the best ratio of depth of winding to depth of armature core; we compared the performance of smooth and toothed armatures running in similar fields, having regard to the heating of the poles due to the teeth and the increase in the gap necessary to eliminate the same; we demonstrated that compound-wound dynamos could be made to give constant pressure within wide limits of speed, though for each speed there was of course a different pressure, and so on. Again, the heating of dynamos was fully investigated, and the necessary cooling surfaces for armature and fields were arrived at. There is no need to give the results of all this work, as most of them were published at the time and have since appeared in numerous textbooks.

When the Hopkinsons reconstructed the Edison dynamo in 1883, it was realized that the proportions of most machines could be improved. Crompton had discarded the Bürgin machine and designed an excellent one of his own, Fricker overhauled the Gülcher machine, while Mordey evolved a good 4-pole "Victoria" machine out of a bad 2-pole Schuckert machine, etc. Considerable improvement was everywhere apparent, but in 1886 we were still using empirical formulæ to express the magnetic flux in terms of the magnetizing current. In his interesting paper* on "The Predetermination of the Characteristics of Dynamos"—Kapp employed a modification of Frolich's formula, but in the same year the Hopkinsons swept all empiricism aside and in their Royal Society paper employed, for the synthesis of their characteristic, the magnetization curve actually obtained from samples of the iron they employed. From that time designers have followed their example.

The transformer appeared in 1882 as a constituent of Gauland and Gibbs' system of distribution, when it was called a "secondary generator," but it was not until 1885 that it was taken seriously, by which time the engineers of Ganz and Co., had worked out the transformer system of distribution as we know it to-day. It came in the nick of time, because just then the 3-wire system for 110-volt lamps was beginning to find its limit as regards distance from the generating station.

Alternators now came to the front and their designers got busy. In 1886 the Westinghouse Co. brought out the type of machine with which the Sardinia-street station of the Metropolitan Co. was equipped in 1889. The armature in this case consisted of an iron drum with flat coils laid on the same, which rotated inside a circle of radial poles. The armature of Ganz's alternator consisted of a large ring of iron wire on the interior surface of which were laid flat coils side by side, and radial magnets mounted on a flywheel rotated inside the ring. Electrically there was no essential difference between those two machines, though in one the field was stationary and in the other it rotated.

In 1888 Mordey designed an alternator with a stationary armature consisting of thin, flat tapered coils lying in a circle, edge to edge, and projecting inwards from a strong cast-iron shell to which they were attached. The machine was unique, inasmuch as the rotating magnet was excited by a single coil, which meant considerable saving in exciting copper and, in this particular design, very little stray field. The armature coils were of copper ribbon wound on a core of insulating material and secured to the inside of the shell by flanges. By this time Ferranti had abandoned the zigzag armature and was also using flat coils wound on a core of insulating material, mounted in pairs on holders secured to a central wheel. Electrically there was again no essential difference between those machines, though in one the field rotated and in the other it was stationary. They were the only alternators constructed with flat coils without iron, but as a type they have long ago ceased to exist.

Since designing began to be scientific it had been held as an axiom that the magnetic flux through an alternator core should not be subject to variation consequent on the change of position of the field system during the cycle. That meant that the armature core was to have a smooth surface, or if there were to be slots or projections these were to be distributed over the surface so that the flux from the poles was not periodically increased and diminished by their presence. Notwithstanding this, in 1889 Ganz's engineer, Zipernowski, introduced a new alternator with armature protections of a distinctly polar character and at the Frankfort Exhibition in 1891 a 400-kW machine of this type was shown running at

* *Journal I.E.E.*, 1886, vol. 15, p. 518.

125 r.p.m. The field consisted of radial magnets mounted on a flywheel and the armature consisted of a ring with inward radial projections on which the coils corresponding in number with the poles were wound. This alternator remained Ganz's standard till 1897, but, what is more astonishing is that the Hopkinsons introduced in 1900 an alternator built on the same lines. In this machine, however, the field was fixed and the armature rotated, while, due to the better disposition of the magnet and armature poles, the flux disturbance was greatly reduced.

Siemens and Halske's alternator at Frankfort, giving 330 kW at 100 r.p.m., had also an armature of a more or less polar character. The field was as in the previous machine, but the armature core consisted of segments, corresponding in number with the poles, which, when laid together end on, formed a ring. A coil was wound on each segment in the same manner as on the cylinder of the original Gramme alternator, and the iron was channelled out on the inside where the winding came, so that the armature was virtually that of the old Gramme machine with the addition of internal projections between the coils.

Apart from the three-phase work, Frankfort had not on the electrical side any great novelty to show though both dynamos and alternators were of far larger output than any constructed in this country up to that date. The largest dynamo was of the Gramme-ring type with the armature overhung from a star-wheel on 30 insulated steel bolts. It gave 300 kW at 80 r.p.m. and had 10 radial poles fixed inside the ring, the winding on the outside being of bars and forming the commutator. This construction would never have found favour with British engineers, but it must be remembered that while it was the practice on the Continent to couple large machines direct to compound or triple-expansion slow-running engines, it was the practice here to couple to the high-speed engines which had been specially designed to suit dynamos. Accordingly, while in France and Germany the machines were always of multipolar build, here they were nearly always of 2-pole build. The largest dynamos constructed up to 1891 in this country were, if I recollect rightly, the Siemens machines which in that year supplied current to the Naval Exhibition. They were 2-pole and gave an output of 180 kW when coupled direct to Willans engines running at 350 r.p.m. A Continential machine of similar output would have had three times the number of poles and would have run at one-third of the speed.

In 1891 I read a paper on " Notes on the Design of Multi-polar Dynamos " in which I endeavoured to set out the advantages of the multi-polar type. I had designed a considerable number for Paterson and Cooper and continued my work in this direction with the Gülcher Co. and later with Johnson and Phillips though, for the reasons given above, I do not think we ever got beyond 8 poles. Those machines had slotted drum armatures and radial poles mounted on steel yoke rings, and were practically the same as the present designs. The chief point of my paper was, however, that for the first time I endeavoured to put the relationship between the dimensions, speed and output of dynamos on a logical basis and expressed their comparative merits in terms of an output coefficient. This was extended to alternators and later to induction motors and has, I understand, since been employed by most designers.

The electrical feature of 1891 was the transmission of 100 h.p. over 100 miles of line from Lauffen to Franfort by three-phase currents at 8 000 volts, with experiments at a line pressure of 28 000 volts. In the late 'eighties several investigators had been at work on induction polyphase motors and this was the year of their triumph. Manufacturers in this country were slow to take up polyphase work and it was not till 1895 that Kapp designed for Johnson and Phillips the first two-phase alternators made in this country. These were for the Sheba Mine transmission and the armatures consisted of removable segments mounted close together, inside a cast-iron cylindrical shell, and having a coil on each. It was not a polar armature though it has been so described, but a smooth-surface armature with embedded coils. The shell was in halves divided horizontally; the coils on the bottom half supplied one phase while the coils in the top half supplied the other. For the field the single-coil claw-magnet type, used by Brown for the Lauffen transmission, was adopted. Single-phase machines for several central stations had been previously constructed on these lines, but it was soon found that there was no need for removable segments and that the armature coils could better be inserted in grooves on the surface of the core and locked by hard wood keys or wound in slots close to the core surface. This brought us to the distributed winding of the present day and, with radial magnets having a coil on each substituted for the claw magnet, we come to the alternator which has maintained its place for over 20 years.

Above all else stands, in my opinion, the invention and development of Parsons' turbine. From a 10-h.p. infant in 1884, it has grown to be a 30 000-h.p. giant and it is the prime mover for all large steam power-houses. By means of helical gearing, dynamos could be coupled to turbines to run at no greater speed than if they were rope-driven, but alternators were coupled direct to the turbine shafts and had to be specially designed to withstand the great tangential inertia due to the high speed. Accordingly, while the armatures were slotted as already described, the rotating field for many years has taken the form of a drum with the magnetizing coils wound in slots, thus presenting an unbroken cylindrical surface to the armature.

Excluding machines built for isolated installations and power-transmission plants, I was responsible for the machines in about a score of central stations. Many of these attained their majority some time ago, but they are to-day taking their load as they did when first put down. They do not wear out in the sense that boilers, pipes and other plant on the steam side of an undertaking wear out, and it is, in fact, impossible to set a limit to the life of dynamo-electric machinery kept in a proper state of repair. Moreover, the dynamos are not obsolete in the sense that their efficiency is low, because this is within 1 per cent or so of the present-day machines. They are heavier, that goes without saying, but as regards their working they are none the worse for that, and a future regime may see them detached from their engines and coupled in pairs, one on each side of a motor taking a bulk supply at extra high pressure.

SIR R. T. GLAZEBROOK, K.C.B., D.Sc., F.R.S.

The Work of the Third Lord Rayleigh on Electrical Units.

It may be convenient to commence with a brief note of my own connection with Lord Rayleigh and the problems connected with electrical units. He was Additional Examiner in the Mathematical Tripos of 1876 when I took my degree; in 1879, when he became Cavendish Professor of Physics, he asked Sir Napier Shaw and myself to act as demonstrators, and on the reappointment of the British Association Committee on Electrical Standards in 1880 he suggested that I should be Secretary. I worked at the determination of the ohm with Messrs. Dodds and Sargant during 1881 and 1882, and our paper, in which we obtained the value $0{\cdot}98665 \times 10^9$ C.G.S. units for the B.A. unit, was published in 1883 in the same volume of the *Philosophical Transactions* as his determination by the Lorentz method, which gave $0{\cdot}98677 \times 10^9$. In fact, the same standard coils, wound originally by Chrystal, were used by us both, and, as Lord Rayleigh pointed out, the fact that our two results agreed so closely is conclusive evidence of the accuracy of the values given for their radii, for an error in radius affects the two results in opposite directions.

Lord Rayleigh left Cambridge in 1884, but our close connection was continued through the work of the B.A. Committee, while in 1890 we both served on the Board of Trade Committee on Electrical Standards and much preliminary and experimental work, suggested in the main by Lord Rayleigh, was carried out under my direction at Cambridge.

When the National Physical Laboratory was established in 1899 Lord Rayleigh became chairman of the Executive Committee, a post which he held until within a few months of his death in 1919. During that period I was continually in closest touch with him.

Lord Rayleigh became Cavendish Professor at Cambridge on Maxwell's death in 1879. The B.A. units of resistance which were originally constructed by the Electrical Standards Committee in 1867 were at the Laboratory. Chrystal and Saunders had intercompared them in 1876 in the course of their well-known experiments on the accuracy of Ohm's law. Fleming was at work from 1879 to 1881 on another intercomparison and had already arrived at interesting results. Meanwhile the important question had arisen: Did any of the coils really represent 10^9 C.G.S. units of resistance, the value they were all supposed to have?

According to Kohlrausch (1874) they were 2 per cent too great. H. Weber (1878) had obtained by various methods results in close harmony with those of the original Committee, but Rowland (1878) had found that they were nearly 1 per cent too small. Joule also, by comparing the values of the mechanical equivalent obtained by friction and by an electrical method had shown that the value of the B.A. unit was some 1·25 per cent less than 10^9 C.G.S. units.

Rayleigh at once attacked the question. The Electrical Standards Committee was reconstituted in 1880; the original apparatus used by Maxwell and Fleeming Jenkin was transferred to Cambridge, and on 12th April, 1881, a paper on "The Determination of the Ohm in Absolute Measure," by Lord Rayleigh and Dr. Schuster was sent to the Royal Society; it was the first paper of a notable series. As a result it appeared that the value of the B.A. unit was $0{\cdot}9893 \times 10^9$ C.G.S. units and the cause of the discrepancy was shown almost certainly to lie in the wrong value assumed originally for the coefficient of self-induction of the coil, which enters into the result as a large correction.

This was the beginning: it was clear that a higher accuracy was possible; it was clear also that it could not be realized by the old apparatus. Lord Rayleigh, in the discussion* on the Kelvin Lecture in 1913, said that he believed they got in their later experiments an accuracy of 1 part in 1 000. Further work has shown that his figures ultimately were much closer to the truth than this, but more work was needed before certainty on the point was reached. Accordingly a new apparatus of the spinning-coil pattern was constructed, free from some of the defects of the original, and a paper giving the results of the experiments with this apparatus by Lord Rayleigh, Dr. Schuster and Mrs. Sidgwick was sent to the Royal Society on 15th February, 1882. The values arrived at for the resistance of the standard coil at 13° C. from four different spinnings in their third series of observations were 23 613, 23 610, 23 612 and 23 613, a mean of 23 612 with a maximum discrepancy of 1 in 10 000. As a result of these experiments they obtained the value for the B.A. unit of $0{\cdot}98651 \times 10^9$ C.G.S. units, a value lower than that found by Rowland or in their own earlier experiments, but one which enabled Joule's values for the mechanical equivalent as determined by his friction apparatus and by the electrical method respectively to be closely reconciled.

A conference on electrical units had been inaugurated at the Exhibition in Paris in 1881 at which the question of defining the ohm in terms of the resistance of a column of mercury had been vigorously discussed. The Siemens unit, the resistance at 0° C. of a column of mercury 100 cm in length, 1 mm^2 in section, was advocated by Werner Siemens, Helmholtz and others; ultimately it was agreed to adopt 10^9 C.G.S. units as the standard but to express it in terms of the resistance of a column of mercury of definite length, the precise value of which was to be fixed at an adjourned conference to be held in 1882. Sir William Thomson, who was a Vice-President of the conference, was a warm supporter of the C.G.S. units and urged Lord Rayleigh to make his further determination. The result was a paper by himself and Mrs. Sidgwick on the specific resistance of mercury, read at the Royal Society on 4th May, 1882.†

* *Journal I.E.E.*, 1913, vol. 50, p. 591.

† *Philosophical Transactions*, 1883, vol. 174, pt. 1, p. 173. The date is given by a misprint as 1881.

Werner Siemens had found that his mercury unit was equal to 0·9536 B.A. unit. The value obtained by Lord Rayleigh was 0·95418 B.A. unit, which leads to the result, employing his own figure to connect the ohm and the B.A. unit, that the length of the column of mercury required was 106·24 cm. It appeared possible, however, from a discussion of the results of the various intercomparisons of the B.A. unit coils, that Lord Rayleigh's results are represented better by the value of 0·9535 B.A. unit as the resistance of the Siemens unit, and in this case the length of the mercury column representing 1 ohm is 106·31 cm.

A number of other determinations were made, and when the adjourned conference met in the autumn of 1884 Professor Mascart presented a table giving all the figures then known, from which it appeared that the mean was 106·02 cm. The conference accepted this, and its first resolution was: The legal ohm is the resistance of "a column of mercury a square millimetre in section and 106 centimetres in length at the temperature of melting ice."

The English representatives, Thomson, Carey Foster, Preece and others had pressed for a discussion more in accordance with the more recent results. To accept the mean of a series of figures differing among themselves by over 2 per cent was far from satisfactory, and accordingly the "legal ohm" was never formally adopted in England.

Meanwhile, Lord Rayleigh continued his work, and in the *Philosophical Magazine* for November, 1882, published a most important paper on "Comparison of Methods for the Determination of Resistances in Absolute Measure" which led him to the conclusion that "The method which, with the introduction of certain modifications not affecting its essential character, I am disposed to consider the best of all was proposed and executed by Lorentz of Copenhagen in 1873." He had already given practical effect to this conclusion by carrying out along with Mrs. Sidgwick a memorable series of experiments by this method, which was communicated to the Royal Society, December 8th, 1882. These give as the value for the B.A. unit the value $0{\cdot}98677 \times 10^9$, and for the value of the ohm 106·21 cm of mercury. If we take the corrected value for the relation between the B.A. unit and the resistance of mercury this becomes 106·27 cm.

Meanwhile a large number of other determinations were made.

Table VII in the Fourth Kelvin Lecture* gives the results up to the year 1890, and in that year the Board of Trade appointed a Committee on Standards for the Measurement of Electricity for Use in Trade, of which Lord Rayleigh was a leading member. As a result of these deliberations they adopted the value 106·30 cm as the length of the column of mercury having a resistance of 10^9 C.G.S. units. In 1891 the British Association met at Edinburgh and the Committee postponed formal publication of their conclusions until they had been discussed at that meeting.

Helmholtz was present with Lindeck and Kahle to assist him. M. Guillaume represented France and Prof. Carhart the United States. Conferences had taken place previously at Terling, where Lord Rayleigh entertained Helmholtz and some of the others while Lindeck had compared his standard resistances with the B.A. units at Cambridge. As a result the following resolutions were agreed to:

(1) That the resistance of a specified column of mercury be adopted as the practical unit of resistance.

(2) That 14·4521 grammes of mercury in the form of a column of uniform cross-section 106·3 cm in length at 0° C. be the specified column.

(3) That standards in mercury or solid metal having the same resistance as this column be made and deposited as standards of resistance for industrial purposes.

(4) That such standards be periodically compared with each other and also that their values be redetermined at intervals in terms of a freshly set up mercury column.

With regard to the unit of current and of electromotive force which, as will appear below, had been interesting Lord Rayleigh since 1882, it was agreed that the figure 0·001118 should be adopted as the number of grammes of silver deposited per second from a neutral solution of nitrate of silver in water by a current of 1 ampere, and the value 1·434 as the electromotive force in volts of a Clark cell at 15° C. Both these figures were based on Lord Rayleigh's investigations. These results were communicated to the Board of Trade Committee and formed the basis of a Supplementary Report which was made to the Board of Trade in November, 1892. They were also confirmed at an International Conference held at Chicago in August, 1893, under the presidency of Helmholtz, and the names International ohm, ampere and volt were given to the units so defined. Legal effect was given to them in Great Britain by an Order in Council dated 23rd August, 1894.

But to return to Lord Rayleigh's share in the establishment of the ampere and the volt. A current is determined in absolute measure by some form of electrodynamometer of which the constants can be calculated from its dimensions. Joule and others had used a current balance; the B.A. Committee had constructed an electrodynamometer consisting of a pair of small coils carried by bifilar suspension within a pair of larger coils.

In a paper read before the British Association at Southampton in 1882 Lord Rayleigh discussed the matter and pointed out the advantages of the current weighing method; he showed in particular that it was not necessary to know accurately the radii of the fixed and movable coils, provided that their ratio could be determined with exactness, and he indicated a method (due to Bosscha) whereby his could be done electrically. With the assistance again of Mrs. Sidgwick, he at once attacked the problem, and the results are given in a paper on "The Electrochemical Equivalent of Silver and on the Absolute Electromotive Force of Clark Cells" read before The Royal Society, 19th June, 1884.

He pointed out that there were two ways in which a current might conveniently be measured; electrochemically, by determining the quantity of some sub-

* *Journal I.E.E.*, 1913, vol. 50, p. 572.

stance (say silver or copper) deposited per second from a suitable electrolytic solution; and by comparing the fall of potential when the current traverses a known resistance, with the E.M.F. of a standard cell. Both these methods are described in the paper under discussion. A third method is mentioned and forms the subject of a separate paper; it depends on the rotation of the plane of polarization of light when traversing a liquid—bisulphide of carbon was used—in a magnetic field due to the current.

The paper is a memorable one: the conditions requisite for accuracy in the use of the balance are critically examined; the methods of calculating the constants discussed; the sources of error in the determination of the electrochemical equivalent of silver—the substance ultimately chosen—considered; and the construction of a cell of constant E.M.F.—the Clark cell—described. It occupies 50 pages of the *Philosophical Transactions*; is in itself a mine of exact information; and has been the starting point of numerous investigations of first-rate importance. The silver voltameters used were of the form recommended by Poggendorf; the silver is deposited on a platinum cup containing the electrolyte the while a piece of silver sheet is covered by filter paper. Recent work has shown that this may be a source of error; the value ultimately found for the electrochemical equivalent of silver was 0·00111794 gramme deposited per ampere per second, while the E.M.F. of a Clark cell was found to be 1·435 volts at 15° C. The values for these quantities which were considered by the B.A. Committee at Edinburgh in 1892 are given below.

Electrochemical Equivalent of Silver.

Mascart	0·0011156
Rayleigh	0·0011179
Kohlrausch	0·0011183
T. Gray	0·001118
Potier and Pellat	0·0011192

Electromotive Force of a Clark Cell at 15° C.

Rayleigh	1·4345
Carhart	1·4340
Kahle	1·4341
Glazebrook and Skinner	1·4342

These results led, as has been already stated, to the accepted values of 0·001118 and 1·434.

A paper read before the Royal Society, 21st January, 1886, extended further our knowledge of the Clark cell; this with the paper already mentioned on the "Constant of Magnetic Rotation of Light in Bisuphide of Carbon" read before the Royal Society, 15th January, 1885, completed Lord Rayleigh's own experiments on electrical units. He ceased to be Cavendish Professor in 1885 and his private laboratory at Terling did not afford the same opportunities for electrical work; besides, there was little more to do.

This was, however, by no means the end of his interest in standardization work. He was always ready to help those who were endeavouring to push further the limits of accuracy and to make our knowledge more precise.

The National Physical Laboratory was founded in 1900 and became the home of the electrical standards. Lord Rayleigh was chairman of the Executive Committee. Viriamu Jones had devised a novel form of Lorenz apparatus for McGill University and he and Ayrton had obtained provisional results from its use while with Ayrton he had suggested improvements in the ampere balance as used by Rayleigh. An ampere balance on his plan was set up at the Laboratory by Mather and F. E. Smith and a fresh determination of the electrochemical equivalent made. By this time the Weston cell had superseded the original Clark cell as a standard and Smith's investigation had rendered it a standard of very high accuracy, while the generosity of the Drapers' Company, supplemented by the most valuable assistance of Sir Andrew Noble at Elswick, enabled Smith to design a form of Lorentz apparatus by which he reached in 1911 an accuracy far beyond that previously attained.

In support of all his work, Lord Rayleigh was continually active; his encouragement and interest were of the utmost help, and his knowledge was regularly appealed to in cases of difficulty.

He was chairman of an International Conference on units held in London in 1908 on which all the important nations were represented, and his conduct of the business contributed in no small degree to its success.

The following are the resolutions arrived at, which now form the basis of legislation generally.

(i) The Conference agrees that, as heretofore, *the magnitudes of the fundamental electric units shall be determined on the electromagnetic systems of measurement with reference to the centimetre as the unit of length, the gramme as the unit of mass, and the second as the unit of time.*

These fundamental units are (1) the ohm, the unit of electric resistance which has the value of 1 000 000 000 in terms of the centimetre and second; (2) the ampere, the unit of electric current which has the value of one-tenth (0·1) in terms of the centimetre, gramme and the second; (3) the volt, the unit of electromotive force which has the value 100 000 000 in terms of the centimetre, the gramme and the second; (4) the watt, the unit of power which has the value 10 000 000 in terms of the centimetre, the gramme and the second.

(ii) *As a system of units representing the above, and sufficiently near to them to be adopted for the purpose of electrical measurements and as a basis for legislation, the Conference recommends the adoption of the international ohm, the international ampere, and the international volt defined according to the following definitions:*

(iii) The ohm is the first primary unit.

(iv) The international ohm is defined as the resistance of a specified column of mercury.

(v) The international ohm is the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14·4521 grammes in mass, of a constant cross-sectional area and of a length of 106·300 centimetres.

To determine the resistance of a column of mercury

in terms of the international ohm, the procedure to be followed shall be that set out in Specification I attached to these resolutions.

(vi) The ampere is the second primary unit.

(vii) The international ampere is the unvarying electric current which, when passed through a solution of nitrate of silver in water, in accordance with Specification II attached to these resolutions, deposits silver at the rate of 0·00111800 of a gramme per second.

(viii) The international volt is the electric pressure which, when steadily applied to a conductor whose resistance is one international ohm, will produce a current of one international ampere.

(ix) The international watt is the energy expended per second by an unvarying electric current of one international ampere under an electric pressure of one international volt.

The relations between the international units and the absolute C.G.S. units are as follows:—

1 International ohm $= 1{\cdot}0005_2$ ohms $= 1{\cdot}0005_2 \times 10^9$ C.G.S. units.

1 International ampere $= 0{\cdot}9999_7$ amperes $= 0{\cdot}9999_7 \times 10^{-1}$ C.G.S. units.

1 International volt $= 1{\cdot}0004_9$ volts $= 1{\cdot}0004_9 \times 10^8$ C.G.S. units.

International electrochemical equivalent, 1·11800 mg.

An outcome of the Congress was the formation of an expert Committee known as Lord Rayleigh's Committee, to continue investigations with the Silver voltameter and the Weston cell; some members of that Committee met at Washington in 1911 and by their work settled a number of outstanding points of detail.

In conclusion, it is of interest to give the values for the various constants investigated by Lord Rayleigh as determined by the most recent work.*

* For full particulars reference may be made to vol. ii of the forthcoming *Dictionary of Applied Physics*, in which will be found an article on the subject by Mr. F. E. Smith.

Values of the Ohm.

Observer	Ohm in Centimetres of Mercury
1882. Rayleigh	106·26
1882. Glazebrook	106·25
1883. Rayleigh and Sidgwick ..	106·24
1885. Wiedemann	$106{\cdot}16_2$
1889. Dorn	$106{\cdot}24_3$
1891. V. Jones	106·31
1912. Campbell	$106{\cdot}27_3$
1913. Smith	$106{\cdot}24_5$
1920. Grüneisen and Giebe	$106{\cdot}24_6$

The mean of all these values is $106{\cdot}24_8$, and it appears that within 1 part in 10 000 the ohm (10^9 C.G.S. units) can be represented by the resistance at 0° C. of a column of mercury of the same cross-section as the international ohm and having a length of $106{\cdot}24_5$ centimetres.

Values of the Ampere.

CURRENT WEIGHER METHODS.

	Milligrammes of silver per coulomb
1882. Mascart	1·1156
1884. Rayleigh..	1·11794
1890. Pellat and Potier	1·1192
1908. Ayrton, Mather and Smith ..	1·11827
1908. Janet, Laporte and Jouast ..	1·11821
1910. Smith	1·11815
1911. Rosa, Dorsey and Miller ..	1·11804

A close review of the recent observations leads to the result that the electrochemical equivalent of silver is 1·1181 milligrammes per coulomb.

Values of the E.M.F. of a Weston Cell.

Date	Observer	Form of Voltameters	No. of Deposits	E.M.F. of Weston Normal Cell at 20° C.
				volts
1908–10	Rosa, Vinal and McDaniel	Richards	86	$1{\cdot}01828_1$
1909–10	Smith	Smith and Richards	17	1·01827
1910	International Technical Committee	Smith	8	$1{\cdot}01828_7$
		Richards	14	$1{\cdot}01828_6$
1910	Smith and Vinal	Smith	19	$1{\cdot}01830_4$
		Richards	15	$1{\cdot}01821_8$
1910	Von Steinwehr	Kohlrausch	40	$1{\cdot}01829_0$
1910–12	Rosa, Vinal and McDaniel	Smith	55	$1{\cdot}01826_7$
		Richards	156	1·01826
1912–13	Haga and Boerema	Smith	32	1·01826
1914	Foehringer	Smith	4	$1{\cdot}01829_5$
1916	Obata	Smith	40	$1{\cdot}01826_9$
1918	Obata	Richards	61	$1{\cdot}01826_6$

These values are International volts and lead to the result that the E.M.F. of the Weston cell at 20° C. is 1·0183 International volts. This, it follows from the values of the ampere and the ohm in International units, is equivalent to 1·0188 volts.

It is perhaps sufficient as evidence of the value of Lord Rayleigh's work to compare his figures for the ohm and the ampere with those which result from the most modern, refined methods.

PROF. ANDREW GRAY, F.R.S.

Reminiscences of Electrical Engineering in the 'Eighties.

I am not able, without the sacrifice of more time than there is available, to write down all my recollections of the early days of electrical engineering, or even to put them into anything like logical or even chronological order. The first events of importance were the invention of the Swan and Edison lamps and that of the Faure secondary battery. I was assistant to Lord Kelvin, then Sir William Thomson, when M. Faure in May 1881 brought over from Paris to Glasgow his improvement on Planté's secondary battery, experiments with which roused Thomson's enthusiasm to a high pitch and changed the current of work in the laboratory for a long time. There were things connected with those experiments which were interesting both scientifically and from a personal point of view.

The cells had the appearance of cylinders about 1 foot high and 5 inches in diameter, and from their mode of construction had what then appeared to be an astonishingly small internal resistance. The first experiment made by M. Faure was that of connecting the terminals of one of his cells with a short piece, 2 or 3 feet, of copper wire of about 1/10 inch diameter, which immediately became red-hot and was quickly fused by the strength of the current evoked. Other experiments were made, and the results reported to Thomson, who was just then laid up with a recurring ailment which confined him to bed for two or three weeks. He was intensely delighted, said that at last a dream of his life had been realized in the most complete manner, and that now with the aid of secondary batteries great developments in practical applications of electricity were possible. The laboratory was kept running both day and night. He lay in bed and called for experimental results, which was a little hard on those who had to supervise the laboratory and who really belonged to both "shifts." He sent a long letter to *The Times* of June 9th, 1881, which attracted much attention, and was the subject of a great deal of discussion.

The laboratory staff was now employed day and night in two squads, in the work of making and testing Faure cells. These were made at first by coating plates of lead, about 3 ft. long and 1 ft. broad, on both sides with a paste of minium (red lead) and dilute sulphuric acid, then enveloping each plate in woollen cloth, secured by sewing. Two plates were then laid together, rolled up, and placed in a lead pot containing dilute acid. The plates were cut with "lugs" which formed the electrodes.

An attempt was at first made to charge and "form" the cells by means of a battery of large-surface tray Daniell cells, but a Siemens SD_2 machine was telegraphed for and the cells charged with it. Ultimately a 10-h.p. gas engine—the first made by Dugald Clerk (now Sir Dugald Clerk, F.R.S.)—was obtained, also a much larger machine, and the charging and testing of secondary batteries, which now engrossed the whole energies of the laboratory staff, was much more expeditiously carried out.

Perhaps I may be pardoned for recalling that, in connection with the working of this gas engine, I hit upon the plan of starting which is now in use for the self-starting of motor-cars. The engine was difficult to start; two or three people turning the flywheel frequently failed to get it under way. The idea occurred to me of using the Siemens dynamo, which stood ready joined with a battery of cells for charging, as a motor driven by current from the battery to drive the engine which, after an explosion or two, became the driver of the machine. A current in the opposite direction, a charging current, began to pass, and no alteration of connections was necessary. This is what is now done with the dynamo and lighting battery of the car.

An incident, which I suppose illustrated Thomson's objection to trusting to pre-conceived opinions, occurred in connection with these secondary cells. For some reason we had constructed a long trough capable of containing 8 or 10 cells. Thomson asked me to place in it that number of pairs of plates, say 10, immersed in dilute sulphuric acid, without partitions to separate the cells, then to put the arrangement in a charging circuit and observe the difference of potential maintained in the arrangement between the terminal plates. I ventured to say that the difference of potential would probably be a little over 2 volts, i.e. that of a single cell. "Go and try it," he said, rather impatiently. I did so, with the result that I had predicted. When I reported the result, he made no comment of any sort. I wondered whether Thomson thought that the dilute acid connecting the plates might be made to bear the electric stress involved in the electromotive force of a number of cells in series. The result showed that a conductor such as dilute acid could not endure such a stress.

About this time the question of electrical measurements began to attract attention, and I wrote a series of elementary papers on the subject for *Nature*. These were afterwards translated into French and appeared in *La Lumière Electrique*. They became the nucleus of a small treatise on the subject, which later on, after I had left Glasgow, I expanded into a more complete work. This has just been issued in a rewritten and altered form in a single volume containing many things hardly thought of at that time, for example the distribution of alternating currents over the cross-section of a conductor.

Electricians at this time (the early 'eighties) when electrical engineering was in its infancy, were mainly men whose training had been in connection with telegraphic work. The best of these had been trained in cable work, and were conversant with cable testing. But the novel ideas introduced as dynamo work became more and more important and, as the dynamo itself was gradually developed and more completely understood, were only gradually taken in and appreciated.

I was greatly amused with a certain engineer's attempt to measure the resistance of an incandescent filament when hot. His idea was to arrange a Wheat-

stone bridge, turn on the lamp for a short time, switch off the main current, and, as it were, catch the resistance with the bridge before the filament had time to cool! The idea of measuring the difference of potential on the lamp terminals and the current at the same time through the lamp, had not occurred to him. However, this electrical engineer persevered and ultimately wrote some useful things and did some useful work. His self-confidence and self-appreciation were always enormous, and carried him through many awkward situations where a more modest and even more competent man would have acknowledged defeat.

My work in Thomson's laboratory brought me into contact with many interesting people. We had two completely fitted cable stations with an artificial cable, representing the French Atlantic cable, between them. With this I taught siphon-recorder work and automatic curb sending to men of the Eastern Telegraph Co., and officials of that Company visited the laboratory from time to time. Among these were Saunders, the respected Chief Electrician of the Company, and De Sauty (of De Sauty's capacity test), the hero of the incident in the laying of the ill-fated 1858 Atlantic cable, which is commemorated in Oliver Wendell Holmes's poem of "All right, De Sauty!" V. Helmholtz also visited the laboratory at least twice, once about the time of the secondary-battery work.

The testing of dynamos was done early in the 'eighties by methods which had to be extemporized and carried out with such instruments as were readily available. I made tests of Ferranti alternators, using a quadrant electrometer in a method of my own, which probably occurred to and was used by others. The *Glasgow News* office was lighted with alternating current generated by Ferranti machines. This machine, it will be remembered, was one with an armature made of copper strip "crimped" like the fluted border of the old-fashioned linen cap which used to be worn by old ladies of the humble class in Scotland. The armature was invented simultaneously by Thomson and Dr. S. Z. de Ferranti, who is happily still with us, and a working arrangement was come to between the two patentees. Thomson generally believed in direct current; but he always had a tender feeling for the Ferranti machine which he employed at Peterhouse, Cambridge, and, as I have said, it was adopted at the *News* office. There I arranged for a quadrant electrometer to be used idiostatically for the measurement of the mean-square difference of potential between the terminals, and of the activity, in the manner now well understood. But I am not sure that that was not the first time such an instrument was used for this purpose. I may say that it did not occur to us to publish every little method of testing and every practical experiment made, in the manner that was then rather customary.

Electric lighting began in the 'eighties and at first made slow progress. I was personally much interested in street lighting and electric projects of municipalities. My brother and I held patents for arc lamps and electric meters; one of the latter patents, I was assured 15 or 20 years ago by Professor Perry, would have been, had it been maintained, a master-patent for meters. But the legislation of the time regarding electric undertakings stopped all progress, and it was impossible for any but rich men to keep patents alive until they began to pay. Thus we had to let our patents die; but I have no doubt that the ideas embodied in them proved useful and remunerative later to others. Then, as now, inventors received little consideration; the financial gentlemen, as always, reaped all the profit. A number of papers were published at this time on what was called "the division of the electric light," in which various pretty obvious results of elementary electrodynamics were discussed at some length. These, however, were useful, if of no very high scientific value. Engineers were tackling new problems, and clear statements of what would now be regarded as commonplaces were helpful to the rank and file.

After witnessing trials of the Swan lamp and studying the economics of the subject of lighting by incandescent lamps, Thomson decided to have his house at the University lighted with electricity. It was already lighted by a very good system of self-ventilating gas burners (the Benham system I think it was called), but he was so convinced of the superiority of incandescent lighting that he had his house wired and the whole of the gas fittings cleared away at once. Leads were brought over from the laboratory, where the Clerk gas engine and the Siemens dynamo, with a battery of about 50 secondary cells to ballast the dynamo, were situated. Thus Thomson generated his own electricity, purchasing the gas for the engine from the Glasgow Corporation.

Thomson was strongly in favour of wiring with bare wire, which accordingly was used throughout. To celebrate the completion of the installation and display the electric light a large dinner party was arranged for, to which some guests, very important financially and otherwise, were invited. The dinner began but had not proceeded far when, alas! the light went out, was restored, and then was extinguished and restored alternately. A rapid visit to the laboratory revealed the cause, and incidentally afforded a commentary on the use of bare wire. The current was brought to two terminals in the form of two copper rods laid along a table which stood against a wall. For the house-lighting similar terminals were laid along the wall, and the necessary connections when the house was to be supplied were made by means of weighted copper lean-to contact-pieces, extending from the table terminals to those on the wall. At the table a laboratory student was standing, alternately lifting and replacing the contact piece, and enjoying the brilliant coruscations of flame which ensued. A very forcible comment or two cured the student, I should think, for ever, of any desire to pursue further that line of research!

I inherited the house with all its wiring, and the laboratory with its appliances in 1899. By that time a scheme of electric lighting had been adopted in Glasgow, and mains had been laid to most parts of the city. The battery, consisting of E.P.S. cells, was worn out and the starting and stopping of the gas engine at a distance from the house was, to say the least, inconvenient. So I applied to the University Court to have the house placed on the Corporation mains, sold the gas engine, and installed a motor to drive a generator

for laboratory purposes. But the Corporation refused to place the house with its bare wire on their mains, and so it had to be wired according to a specification which I am afraid violated pretty well all Lord Kelvin's ideas of domestic wiring.

Going back again to the 'eighties, I may mention that Dr. John Hopkinson came to Glasgow to experiment with the Edison dynamos, which probably led him to consider the magnetic circuit and evolve the Manchester dynamo. The Edison dynamo had an armature running between pole-pieces at the extremities of long legs which connected them with the yoke. I remember seeing an explanation of this machine, which appeared in an American paper, and was stated to be written by "Mr. Edison's mathematician"! I do not know who this learned gentleman was; but the idea of the long legs—to give the field magnets a large magnetic moment—was clearly irrelevant, and made the machine unnecessarily cumbrous. We tested these machines, I remember, at a small sawmill at the shop of a venetian-blind maker, and had great difficulty getting the steam engine, which was of small power, not suitable for such work, to run steadily. We also went to various places, tailors' shops and the like, where gas engines and dynamos were installed, and made brake-tests of power expended, and electrical tests with various apparatus. The results were useful and instructive to people who were feeling their way to electrical testing in varied circumstances. They were to me of great interest.

MR. F. E. GRIPPER.

The Earliest Days of Electric Lighting.

When I was asked to take part in the Commemoration Meetings and to give some of my early experiences in the development of the electric supply industry, and when I saw the long list of names of those who were taking part, I wondered what particular experiences of my own would be of the most interest to the meeting. I came to the conclusion that they might probably be those of the very earliest days of electric lighting before any public supply was thought of.

In the year 1874 I became the London Manager of Messrs. Edmundsons, who at that time were well-known lighting engineers interested principally in the installation of private plants for the supply of gas to country houses and large establishments in the country where a supply of gas was not otherwise available. At that time not only was there no idea of the possibility of a general use of electricity for lighting, but even the sub-division of the electric current was not generally considered feasible. Within three or four years, however, the probability of electric lighting taking the place of gas for many purposes began to come seriously under consideration, and I was convinced that it would not be very long before the business of providing private gasworks would be seriously threatened. I began, naturally, to take great interest in every development of electricity as applied to lighting purposes, and I convinced my company, not without considerable difficulty, that it was desirable that we should be in the forefront of any developments which might take place in this direction. At that time (in the late 'seventies) electric arc lighting began to be introduced for the illumination of streets and large areas, but such lighting was still in the experimental stage and was carried out largely for the purpose of advertising the progress which was being made. Some years earlier my company had installed one of their very large Wigham lighthouse gas-burners in the clock tower of the House of Parliament for the purpose of acting as a signal when the House of Commons was sitting, and I remember that one of the earliest attempts which I made in electric lighting was in the experimental lighting of the Central Hall of the Houses of Parliament—I think about 1878. This was carried out by means of two Serrin arc lamps which were supplied by two Gramme arc-lighting dynamos. This experiment was really only an advertisement of the progress of electric lighting. Much interest was shown by Members of Parliament and others, but the illumination of the Hall, of course, left much to be desired, and no direct results followed.

About the same time the introduction of the Jablochkoff candle carried things a step further in the direction of providing lights of smaller candle-power. Much interest was aroused, with little result towards the use of electric lighting for general purposes. I remember carrying out a temporary installation for a few days of two circuits of Jablochkoff candles (I think 12 in all) on the parade at Birchington, then quite a village. This installation, curiously enough, was made at the instance of a gentleman very largely interested in gas undertakings and was for the purpose of calling attention to the place in question with a view to early land development. A special train was chartered to take down members of the Press and other interested parties from London to see this novel application of electricity. The lighting was carried out by means of a portable steam engine and a De Meritens generator, the supply cables being temporarily attached to the iron railings which ran for about half a mile along the sea front. The lighting was quite successful and made a great impression upon the visitors. Naturally, after the inspection a dinner took place at the newly erected hotel, my own enjoyment of the banquet being somewhat marred by a message which came to me in the middle of the dinner that all the lights had gone out. A heavy storm of rain did not agree with the temporary arrangement of the cables on the iron fences. Fortunately the visitors were not anxious after dinner to resume any further inspection in the rain and returned to their special train and to London without any idea that anything untoward had happened. Since those days the village has certainly developed into a town, but I am doubtful as to how much credit can be taken by electricity for this result.

About the same time, the earliest examples of incandescent filament lamps began to be shown and talked about, with the result that people hesitated

to install private gas lighting plants in view of the possible early developments in incandescent electric lighting. The first incandescent electric lamps were put on the market by Swan, and I remember purchasing a number of the very earliest examples at the price of 25s. each and experimented in lighting my own offices with these, run, I think, about eight in series from a De Meritens generator driven by a gas engine, with the result that the expense of the frequent breakages of these expensive lamps was very depressing. This was, I think, about 1879. At that time there were no generators which were suitable for running incandescent lamps in parallel, there were no switches or any other accessories to be purchased, and workmen had to be trained to carry out work which those who tried to train them knew very little about themselves.

Another year or two showed a great advance. Swan lamps were obtainable for 5s. each, and quite excellent dynamos suitable for running lamps in parallel were designed by Siemens and others. Switches, ceiling roses and fuses I improvised of a type that would now be looked upon with horror, and some of my gasfitters became very good electrical wiremen.

In 1881 (the year in which I became a member of the Institution), I carried out one of the earliest installations of incandescent electric lighting for the country house of the late Lord Amherst, of Hackney, then Mr. Tyssen-Amherst. Some 250 lamps were installed, the motive power used being a gas engine supplied from the private gasworks which we had erected many years before. Dynamos made by Siemens were used. I do not think this was quite the earliest example of a country house being lighted, as I believe a slightly earlier installation had been carried out for the late Lord Armstrong. As at this time no storage batteries were available, the lighting had to be shut off during the night until storage batteries made by my friend Bernard Drake were available for practical use, and were added to every country house installation. I well remember my first experience of installing a storage battery and having to break down to the correct specific gravity the heavy sulphuric acid which had been sent down—I presume for the purpose of saving the expense of carriage. A large number of beautifully glazed earthenware dairy pans were requisitioned from the dairy on the estate, and the feat was accompanied with much damage to the pans and probably also to the life of the battery, owing to the length of time which the operation occupied.

In 1883 I carried out quite a number of large private installations throughout the country, and it was possible to obtain portable storage batteries of quite large capacity, capable of supplying temporary installations for balls and parties. These were charged at the maker's works and sent long distances by road or rail. The only things which really gave me no trouble in those early days were the cables and wires. These were insulated with pure rubber of most excellent quality, manufactured by the India Rubber and Gutta Percha Company, of Silvertown, and although laid in most primitive fashion, cleated on the surface of walls, threaded through wooden joists under floors and only covered in wooden casing where exposed to the probability of damage, the work then carried out stood the test of many years and some of it is, I have no doubt, still in existence. It makes me wonder sometimes whether all the elaborate precautions laid down by our modern Wiring Rules are not somewhat overdone, and whether we might not with advantage save expense and take a little more risk. In all my experience I only remember one really serious fire being caused by electric wiring, and that one was really caused by the breaking-down of a house transformer. The high-tension current got across on to the low-tension house circuits, and from these on to a gas pipe, fusing a small hole in the gas pipe and leaving a jet of gas burning, which started a very serious fire.

From the year 1883 onward, private installations of electric lighting were installed throughout the country, both for country and town houses, and I have never erected a private gas-works since that date. The motive power in the country was nearly always a semi-portable steam engine, unless, as in a very few cases, water power was available. In towns, engines worked from the town gas supply were nearly always used. These early installations as compared with those of to-day were handicapped by the comparatively large amount of power which had to be installed to provide a supply to the 4-watt lamps of that period, practically four times as much power being generally installed as would be needed to-day. Some of these early private installations remain very much as when at first installed, although, of course, most of them have been re-modelled and brought up to date. Of the private installations in London and the large towns, or those within the reach of a public supply, almost all have gradually disappeared in favour of a supply from the public mains; a large number of private plants are, however, still being installed in places which are beyond the reach of a public supply, and owing to the smaller power now required, such plants are practicable for quite small country establishments.

MR. KILLINGWORTH HEDGES.

Early Experiences of Electricity Supply.

In April 1879 I visited Paris in company with the late Mr. William Strode, in order to see the so-called "battle of the lights," the Avenue de l'Opera being illuminated by Jablochkoff electric candles (first exhibited in this country by Messrs. Wells & Co., of Shoreditch), and the adjoining Rue 4th Septembre, by Phare gas burners. The latter appeared to me to give the better result, and I returned with a few lamps, some of which were erected facing the Mansion House station and others at the foot of St. James's-street. I may therefore claim to be one of the pioneers of modern gas lighting.

My first electrical installation on a large scale was commenced in the same year when I acted as con-

sulting electrical engineer to the Mersey Dock and Harbour Board, and designed and carried out the temporary lighting used in connection with the construction of the Langton and Alexandra Docks, and afterwards for the permanent installation, which consisted of 4 double Gramme machines working 8 Serrin lamps of 6 000 c.p. each, and suspended from lattice towers. These dynamos were purchased from Sautter Lemonnier, in Paris, and were still working successfully, I think, up to 1900, the Serrin lamps having, of course, been superseded. A lamp of my invention was also used, in which the carbons, two positives meeting at an apex, and one negative (the latter held by an iridium stop) were loosely supported in a tube; this and Rapieff's previous design were the pioneers of the present magazine lamp. The cable to the towers was run by the side of the hydraulic mains, and the latter were used quite successfully for the return circuit to the dynamos.

A scheme in which I assisted was put forward later by the Board for an overhead railway, but was abandoned owing to the opposition of merchants who were concerned as to the danger from fire.

At the 1881 Paris Exhibition the general topic was the division of the electric light by Edison. Mr. Werderman had already shown a number of lamps in series, in which the light was produced by the incandescence of a very fine rod of carbon lightly held against another rod of much greater area. The André lamp was of more practical form but similar in character. About a dozen of these lamps were installed on the s.s. "Chimborazo" in 1880 and supplied from an "A" Gramme dynamo, which was driven by the first Willans engine used for this purpose, constructed by Messrs. Hunter and English at Bow. The contractors were the British Electric Light Company.

A switch which I invented was very popular, and was selected by Messrs. Crompton & Co. for turning on the lights at the opening of the Crystal Palace Exhibition in 1882, by, I think, the Lady Mayoress.

In 1883 I formed a small business under the name of the Electrical Supply Company with works in York-street, Westminster. The manager was Mr. W. Bridges Adams. The principal work was the manufacture of switches and fuses of mica foil and other supplies such as boxwood, ceiling roses, and cut-outs. Mr. Henry Chapman, founder of the General Hydraulic Power Company, had obtained the English patents for the Baillie accumulator, the features of which were a porous pot containing a zinc electrode made by moulding zinc filings under pressure with mercury. Outside the pot were strips of sheet lead shaped like a comb and formed by the Planté method. This zinc-lead couple gave a higher voltage, and was also lighter, than lead alone. The principal business was with small cells, each containing a round porous pot; these were arranged in wicker baskets, with the idea of delivering electric light to consumers daily. I remember giving a dinner at my rooms, 25, Queen Anne's-gate, when Mr. B. Baker (afterwards Sir Benjamin Baker of Forth Bridge fame), Mr. J. C. Graham, Q.C. (now Judge Graham), and several others were present, and astonishing them by lighting the room with three 10-volt Swan lamps. The basket with the so-called accumulators was at first placed in the corner, but was soon removed owing to the hissing noise and smell.

In 1886 I visited India, and having been asked privately to report on the Brush installation for lighting the Markets in Bombay, I especially noticed the overhead insulated cables and reported that I did not consider them suitable for the Indian climate; this was justified later and they were all removed.

The Electric Lighting Regulations Act was then being considered by the Indian Government. I had several interviews with Sir Theodore Hope on the clauses to be inserted to obviate accidents from fire and shock.

I had also been requested to report on the introduction of the electric light, and before my visit terminated I had obtained concessions for the most important Indian cities, except Bombay. On my return to this country the Orient Electric Light Company, Ltd., was formed.

The next difficulty was to obtain plant, a few dynamos and the usual portable engines were shipped under the care of Mr. Grimshaw, a pupil of Messrs. Crompton. Mr. Grimshaw carried out several private installations and exhibited the electric light in several cities. The small arc lamps, however, were not reliable, so that there was not much to be done in the way of interior lighting, in fact the Company was rather too early in the field to command financial success, and Mr. Grimshaw was recalled—much to his advantage, for he soon joined the Westminster Supply Company and has acted as their Engineer up to the present time.

In 1884 the Hammond-Wright system was adopted for part of Brighton, overhead wires being suspended between lamp standards and over roofs. Mr. Hammond asked me to give evidence in support of the proposal to work the station by means of gas engines and underground cables. A scheme was put forward by Alderman Hallett to install gas engines. He said that two, each of 21 nominal h.p., with a third in reserve, would be sufficient for 2 000 lamps. I ventured to doubt this. I was accompanied by the late Mr. F. Ince, and we were politely told by the Chairman that we knew nothing about the matter. However, not long after the Inquiry the overhead cables were removed and the municipal station was erected.

With regard to the formation of the Westminster Supply Corporation, a small brick building was erected on the waste ground at the back of Victoria Mansions, and two "A" Gramme machines were driven by one of E. R. and F. Turner's portable engines, and my inclined carbon lamps and other makes were nightly lighted in a small showroom (now the entrance to Lyons' Restaurant) in Victoria-street, and attracted considerable notice. Mr. Browne Martin, the landlord of the property, was specially interested and was joined by Mr. Roger Wallace, Q.C., who held many consultations with me as to the desirability of applying for a Provisional Order for lighting the district of Westminster. A request for an Order duly came before Major

Marindin at the Inquiry held at Caxton Hall in 1889. I remember being cross-examined by the eminent counsel, Mr. J. C. Graham, Q.C., who asked me if I knew anything of a certain book on the electric light and whether the statements therein could be relied on. I was much relieved to find he quoted from my early work "Useful Information on Electric Lighting." The opposition counsel asked what was the capital of the proposed undertakers, and in spite of this being nil, as we had all given our services, the Order was granted on August 26, 1889.

The "Dynamicables."

Very good fellowship was established in the early days among the members of the electrical profession by the monthly dinners of the "Dynamicables," a society —I was an original member—founded by Mr. W. D. Gooch in March 1888 under the name of the "Electric Arc Angels," the name given to a few electrical engineers who used to meet and dine informally at the old Aquarium, a pretentious building which reached from Princes-street to Dartmouth-street, Westminster.

At a meeting of the "Electric Arc Angels" held on the 18th May, 1883, Mr. R. E. Crompton in the chair, Mr. C. E. Spagnoletti, the electrician of the Great Western Railway, proposed that the name should be changed to the "Dynamicables."

The dinners were continued until 5th April, 1889, but from that date until the 20th April, 1904, no meetings or dinners were held. In 1904 the Society was revived and has since maintained an active life.

The Attendance and Minute Books, which were signed by many distinguished persons, are in the possession of the Secretary (Mr. R. H. Tree) of the resuscitated club.

MR. H. HIRST.

My connection with the electrical industry dates back to the year 1882, when I joined the Electrical Power Storage Company in a subordinate capacity. That Company had just been formed with a capital of £800 000 to exploit the Faure, Sellon and Volckmar accumulator patents. I was engaged partly at the office and partly at the works at Millwall; and in both departments I learned mainly how not to do things. At the Head Office it seemed to be nobody's business to look after the securing and execution of contracts. The principal installations which were carried out—such as the Grand Hotel and the Gaiety Theatre—were for the purpose of advertisement. They were demonstrations intended to inspire newspaper articles and so create a movement in shares or assist negotiations for the sale of foreign patents. "Electricity will be brought to our houses with the milk in the morning" was the watchword.

While the management was preoccupied in such directions, it was left to subordinates like myself to receive ordinary mortals who wanted to buy a few cells or to know their dimensions, charge or discharge capacity, or something about delivery or construction.

It was in this office that I first met Mr. (now Sir William) Preece, Professor Silvanus Thompson, Lord Kelvin, Mr. Houghton (engineer of the Brighton Railway), and Mr. Vaudrey of Liverpool. My desire to be of service to them brought me into touch with the works at Millwall, which although ill-equipped were run by very enthusiastic men. Anthony Reckenzaun, the chief engineer, was occupied not only with the development of accumulators but also with the design of a motor for an electric tricycle to be shown at an exhibition in Vienna. Another of his efforts was an electric motor for a boat which made an historic passage up the Thames from Millwall to the House of Commons, and took a number of Members of Parliament for short trips. This pioneer electric boat subsequently crossed the Channel. I believe that Reckenzaun was the first to design the motor control gear which was afterwards so generally adopted on electric tramcars. For about 10 years afterwards his assistant engineer, Elieson, played a very important part in the development of both accumulators and motors for traction. Several omnibus companies were formed under his ægis, and although they were a financial failure they yielded valuable experience and led to considerable advances in the design and construction of electric motors and accumulators. Through Reckenzaun I made the acquaintance of Gisbert Kapp, then of Crompton-Burgin fame. The friendship that sprang up between Reckenzaun and myself led to my request to be transferred to the works. There, however, my knowledge of languages prevented me from becoming a proficient engineer.

It must be remembered that in the early 'eighties the electrical industry was much further ahead in England than in any other country. The fascination exercised on the mind of the public by the new source of light and power was so great that big sums were forthcoming for developing the industry in England while other countries were still hesitating. In consequence, every inventor of an improvement in a cell brought it to England—naturally to the Electrical Power Storage Company. Thus I met Julien, Faure, Philippart, and a number of early pioneers, and I was kept busy translating their specifications and interpreting their wants to our engineers, instead of pasting minium and litharge into lead frames.

Among the visitors from abroad were Oscar von Muller, Rathenau, and Deutsch, the directors of what is now the Allgemeine Elektricitäts Gesellschaft, then called "The German Edison Company for Applied Electricity." It was my duty to conduct them over the works, show them interesting installations, and also take them to the electrical factories then existing, such as the Swan Lamp Works, the Brush Works and Silvertown, and they were amazed at our enterprise.

I well remember their surprise and incredulity when I spoke of the Gaulard & Gibbs transformer which appeared about that time, and their amusement at the audacity of our inventors and the buoyant faith of our investing public. Needless to say, not many years passed before the Electrical Power Storage Com-

pany had to be reconstructed. An able manager, in the person of Mr. Bernard Drake, was appointed, and I left the firm. I was disappointed but not disheartened by my failure. In 1884 I accepted a position with the Electrical Apparatus Company, which was exploiting an electric gas-lighter, the invention of a Mr. Coates, who is still with the General Electric Company, Ltd. The Company also made medical coils, electric bells and other electrical apparatus. I was engaged to open a branch in Australia with £5 000 worth of stock, but this plan was abandoned on account of the Australian Bank crash which then occurred. We therefore decided to open a shop in Queen Victoria-street for the disposal of the stock. No supply companies were then in existence, and the current required in this shop was obtained from a Paterson & Cooper or Siemens generator driven by one of the first Otto gas engines brought to England. In those days a merely electrical shop was a curiosity, and brought all kinds of inquirers and potential buyers.

Besides liquidating our stock I took an extraordinary variety of orders, which proved that my courage was greater than my knowledge: a contract for a battery and motor; an electrically-steered balloon which was sent up at the Crystal Palace; an electrically-driven dog-cart for one of India's Maharajas (subject to a test run between Blackfriars and Charing Cross); a big order for a whole range of electrical instruments and novelties for a British Expedition to Central Asia, intended to impress and mystify the natives; and so on.

One of my frequent visitors was Sir Morell Mackenzie, the great physician, under whose guidance we constructed what I think was the first useful laryngoscope. A frequent visitor was a Mr. Ferranti telling me of the activities of a wonderful son of his (Sebastian Ziani) who, amongst other things, had just invented an instrument "which could measure electricity."

At this period a number of electrical manufacturing companies had sprung up—the Gülcher Company, the Pilsen-Joel Company, the Brush Company with its subsidiaries, Elwell Parker and the various house-to-house supply companies founded by Mr. Robert Hammond. All these companies, however, were concerned with the production of only one or two specialities—either dynamos or arc lamps—on which they concentrated their energies. Many a contract was spoiled or lost through inability to obtain the rest of the necessary materials at the right time. In their search for help I met Colonel Crompton, Mr. W. C. Mountain, Mr. Swinburne, Mr. Esson, Mr. Trentham and others, and I made it my business to find sources of supply for them both in this country and elsewhere.

The General Electric Company, Ltd., over which I preside to-day, arose out of the demands of these engineers. Casing, flexible wires, lamps, small motors, supplies of carbons; these were all wanted, and nobody seemed to know where to get them. Glass shades, lampholders, nipples, galleries, cleats, flexibles, ceiling roses, cut-outs, switches, and a host of kindred accessories, even tools, had to be specially ordered and made for each installation. Each completed installation was an event of almost national importance and formed for a time the subject of a pilgrimage from all parts of the country. I realized the value to the industry of a stock of these commodities; and in selecting or cataloguing them I was compelled to fix on certain standards, as most of the items had to be used in conjunction with others. The Engineering Standards Committee, which has done so much useful work in recent years, little knows how much I was unconsciously responsible for some of their troubles: perhaps I may have saved them some also.

I started inventing, and one of my first patents granted was for china bases for the use of switches, cut-outs and ceiling roses. I was not very successful at first, as china could not be screwed. Rubber rings to hold on the covers, and lock-nuts exposed at the back to hold the plates, proved fatal. I made frequent personal visits to the potteries, glass works and slate quarries for the purpose of pointing out to these industries their opportunities in connection with the development of the electrical industry.

The majority of electrical appliances and accessories were obtainable in this country but, taking advantage of the strong masonic feeling existing among the electrical engineers of all countries, all anxious to help each other, I visited the Continent. There I met Professor Aron, who had just invented an electricity meter based on the difference between the rates of speed of two clocks, one of which was influenced by an electro-magnet. On introducing this meter in England I was met with a claim for infringement from Professors Ayrton and Perry, who had designed an "Erg-meter." An interview with them not only settled the specific point at issue, but marked the beginning of a lifelong friendship with both of them. Crompton, Professor Kennedy, Holmes of Liverpool, J. E. H. Gordon and Bailey were amongst the first to appreciate the importance of this apparatus.

I also visited Schuckert's works and there saw, for the first time, vertical-reading ammeters and voltmeters. These instruments were a revelation to the engineers of this country, as up to that time they had used only horizontal scales. There was no particular patent in vertical-reading instruments, and Messrs. Goulden & Trotter were the first to copy them and introduce them in a greatly improved form.

Whilst at Schuckert's works I witnessed the testing by a Prussian Military Commission of the first search-light for the Prussian Army. I ordered two similar sets and introduced them to the British War Office, which accepted them and sent them out to the Sudan. Some time afterwards I was shown a letter from Major Kitchener, as he was then, full of praise for this wonderful invention which enabled one to sweep the battlefield with light in the evening and come to the rescue of the wounded who had been left behind in the heat of the battle.

The Admiralty also interested itself in searchlights and for a long time it bought, I believe, only Schuckert projectors. I had nothing to do with the transaction and never acted for Schuckert, who started his own agency in England. When, a few years afterwards, the Suez Canal allowed the passage at night of all boats equipped with projectors, the searchlight industry became firmly established in England.

Whilst at Nuremberg I also visited Schmelzer's

carbon works. I think he was the first who produced soft-cored carbons; until then nearly all carbons used in England, except those produced in Mr. Killingworth Hedges's factory, came from America and were copper-coated. The introduction of these carbons led to the development of the magnetically-controlled arc-lamp in place of the clockwork arc-lamp then universally in use.

Representing as I do to-day one of the foremost electrical engineering concerns in the country, I thought that this record of some of my experiences of the earliest days of the electrical industry would throw some valuable light upon the peculiar conditions under which the pioneers of the industry carried on their work.

MR. J. H. HOLMES.

Although my reminiscences relate almost entirely to the "heavy" side of electrical engineering, I can endorse from my own experience the remarks made by Mr. Evershed as to the profound sensations evoked when, for the first time, one heard the human voice, produced by an iron diaphragm actuated by an electric current, transmitted from a distance along a conductor.

The first public exhibition of the telephone in this country was at the meeting of the British Association, at Plymouth in 1877. I was not present at this meeting, but very soon afterwards, in the autumn of that year, when I was an apprentice, I first made a working drawing and then constructed a pair of Bell telephones, which worked satisfactorily from the start, when a friend and I conversed from my sitting-room on the ground floor to a bedroom at the top of the house. The fame of these telephones quickly spread locally, and for a long time any invitation I received to a social gathering was supplemented by a postscript reading "Please bring your telephones with you." Provided with them, and a coil of flexible wire, I had to play the part of entertainer, and scores of persons heard the electrical transmission of speech for the first time by means of those very instruments.

The current produced in the line by the vibrations of the diaphragm must have been very minute, and had it not been for the invention of the microphone by Professor Hughes in May, 1878, the telephone would have remained little more than a curiosity. I remember very distinctly my excitement and astonishment when, in May, 1878, I found in *Engineering* a description of an electrical instrument so absurdly simple, so easy of construction, and so obviously complementary to the telephone, that I lost no time in making one. It was so sensitive to small vibrations that, as was pointed out in the article referred to, not only could articulate speech be transmitted but sounds could apparently be magnified so that there was no difficulty in hearing the "tramp" of a common housefly.

In February, 1878, the tinfoil phonograph of Edison was shown in England for the first time at the Royal Institution, and a few days later it was shown (although being in no way electrical) at a meeting of the Society of Telegraph Engineers, where it evoked the utmost astonishment and interest in all who heard it. In the summer of that year I designed and made a tinfoil phonograph with one diaphragm fitted with an agate point, used both for recording and reproducing the words spoken into it. This instrument, together with the pair of telephones I have mentioned, are now in the waiting room of the offices of my firm in Newcastle, and are still in working order.

To turn now to the "heavy" side of electrical engineering, my practical acquaintance with dynamos and electric lighting goes back to a fairly early date but was not continuous, as not until 1881 did I transfer my energies from the mechanical to the electrical branch of engineering. It was, however, at the beginning of 1877, when I was serving my apprenticeship with Messrs. Head, Wrightson & Co., of Stockon-on-Tees, that I had the good fortune to assist in the first installation of the electric light in their bridge-building yard. The firm had in hand an urgent order for a railway bridge over the River Sutlej, in India, and, to enable the work of construction to proceed by night as well as by day, they decided to try the electric light, which had just been successfully used in the erection of the first Tay Bridge. The Siemens system was chosen, and the dynamo was the 61st machine turned out of the Berlin works of Messrs. Siemens & Halske. It fell to my lot to assist the fitter who erected the machine and wires, and I had to supervise the working of the arc lamp. The dynamo was series wound, with the limbs of the double horse-shoe magnets lying horizontally; there were 8 sections in the commutator, with easily renewable faces to the segments, and the brushes were not unlike the real article bearing this name, as they consisted of straight, round copper wires lying closely together in a double layer, and soldered together at one end. (As late as 1883 they were called "combs" in the makers' catalogues.) The brushes were held in adjustable spring holders so that they lay tangentially to the surface of the commutator and made contact with it at a point about $\frac{1}{4}$ inch from the end of the brush. There was no switch of any kind in the circuit, but as the dynamo was fitted with fast and loose pulleys, and was driven from a line shaft, it could easily be brought to rest in the event of it being necessary to shut off entirely the electric current. There was only one circuit from the dynamo, and in this circuit was a single arc lamp fitted with a metallic parabolic reflector. The lamp was of the Hefner Alteneck type with the mechanism below the arc, which was "struck" by the agency of a vibrating armature acting through a pawl upon a ratchet wheel; the carbons came together by gravity. An article in a Stockton paper, dated 30 March, 1877, described how a torchlight procession of the members of the fire brigade proceeded, accompanied by a brass band and a large crowd, to the works at Thornaby to inspect the electric light and the machinery for producing it. The reporter went on to say: "The wonderful electric light was to be seen in all its brilliant splendour, shining like a little moon on a cloudless night; it cast a light so bright that one could pick up a pin in the

yard, though it was then about 10 o'clock at night. The glare of the furnaces at the other side of the river was rendered dull by the superior brilliancy of this new scientific luminary." The dynamo I have described may still be seen at the works of Messrs. Head, Wrightson & Co.

In 1878 I visited the International Exhibition in Paris, when the electric light in arc form was much in evidence, and the Place de l'Opera was lit up by Jablochkoff candles. The Gramme alternating-current machine was the one generally used for these lamps, and it is interesting to note that it was really a four-phase alternator, but the 4 circuits differing in phase were kept separate. The Jablochkoff system was used in the early part of 1883 for lighting Warkworth Harbour, Northumberland, and I remember having to rewind some of the stator coils of the Gramme alternating-current machine in use there.

I was present at the lecture delivered in Newcastle in the autumn of 1878, when Mr. (afterwards Sir) Joseph W. Swan first showed one of his incandescent lamps in public, and also at the lecture he gave in the same place in October, 1880, when the lecture theatre was illuminated by 20 Swan lamps supplied with current from his premises in Mosley-street. Very soon after this lecture Swan lamps were installed at "Cragside," Rothbury, Northumberland, the seat of Sir W. G. (afterwards Lord) Armstrong, who wrote a letter to the *Engineer* on 17 January, 1881, describing the installation, and mentioning that he commenced to use the lamps about a month previously. There is no doubt that "Cragside" was the first dwelling-house to be lighted by incandescent electric lamps. It is worthy of note that the electric current was generated by a dynamo driven by water power and that it was transmitted 1 500 yards to the house. In the daytime the dynamo was occasionally used for supplying current to an electric motor driving a saw mill.

The International Exhibition held in Paris in 1881 undoubtedly proved to the general public that electric lighting had come to stay, and confidence in it and its future was further supported in this country by the Exhibition held at the Crystal Palace, 1881–82. Many electric lighting companies were started, and I find from a list in a copy of a financial paper, dated 24 June, 1882, that at that date they had a total capital of nearly £18 000 000, and an issued capital of nearly £11 000 000. Many of them had nothing of real value, and I well remember visiting the showroom of the J. B. Rogers Company in Holborn Viaduct, where his system for subdividing the electric light was shown. At each junction box were pairs of hollow copper globes, to the surface of which the ends of the wires were clipped, thus, according to the inventor, ensuring the even distribution of the current. This company had a very short existence.

The first steamship to carry electric arc lamps for interior illumination was the s.s. "City of Berlin," and the s.s. "City of Richmond" was the earliest instance of the electric lighting of a vessel by the incandescent system, and was completed in June, 1881. Very soon after this date the s.s. "City of Rome" was fitted with a very complete installation by the late Mr. John S. Raworth, on behalf of Messrs. Siemens Bros. & Co. I joined his staff and assisted with the work, and was present at the first trials. I remember one rather alarming occurrence. We did not know much about fuses, and when we started up the plant I was horrified to see sulphurous smoke from the vulcanized rubber on the cables, rising from the top of the dado all round the music saloon, and turning the recently finished white-lead painting to a streaky black. I rushed off to the engine-room to get the current turned off (we had no switches nearer) and, being thankful that we had not set the ship on fire, we bribed the painters to work all night to eradicate all evidence of the mishap. The vessel was wired on the single-wire system (Mr. Raworth's invention), the hull of the vessel being used as the return circuit. We made designs for the fittings, which have for the most part survived to this day and have become standard patterns for ship work. When the fitting was fixed to wood-work we ran a bare copper wire from under the metal base of the fitting to the nearest bare ironwork of the hull, but, if this was far away, a strong wood screw, screwed well home until its point pressed hard against the skin of the ship, sufficed for the earth connection!

The Swan lamps, as supplied by the makers, had long glass stems embraced by paper tubes carrying the two contact clips for the double wire holder, so our first job was to replace these tubes by brass ones to the inside of which one terminal wire of the lamp was jammed by a wooden plug, with a hole through it, fitting into the lower end of the tube. Into the hole in the plug we screwed a brass tapered ferrule making contact with the other terminal of the lamp, thus producing a concentric arrangement. The fittings were tubular and had wooden base blocks, carrying in the centre a small brass rod, tapered at the end, to which the insulated wire was screwed; the lamps had merely to be pushed into the fitting to make contact and complete the circuit through the filament. The Swan lamps, which cost 35s. each, came to us in separate wooden boxes the size of large cigars boxes, with elastic bands stretched from side to side on which the lamps were hung so as to avoid shocks, but even then the percentage of breakages was often as high as 30.

The generators on these early steamship installations were usually the Siemens single-phase alternating-current machines with exciters, and Mr. Raworth devised a method of driving by an endless single cotton rope which passed from the first groove of the flywheel to the corresponding groove of the dynamo pulley, then to the second groove of the fly-wheel and the second groove of the pulley, and so on, including the grooves of the exciter pulley, the rope being finally led back to the first groove of the flywheel by a guide pulley. The switches were known as "keys" and the switchboard as the "keyboard." The latter was very simple, having a pilot lamp for voltmeter, and no ammeter, as a suitable instrument had not then been invented. If for any purpose the current had to be measured, we had to do it when the vessel was steady in dock, by means of the Siemens electro-dynamometer; a modification of this instrument, devised by Mr. Raworth for use on board ship, was used

later, and may, I believe, still be seen on some of His Majesty's vessels. The usual voltage of the Swan lamps then used was 47, and as each bobbin of the revolving armature produced about this potential they were coupled up in parallel. For arc lamps they were generally in series, but were easily altered to parallel when a change was made to incandescent lighting, and I had to alter a fair number of machines for this reason.

During 1882, shunt-wound direct-current machines took the place of the alternating-current machines for running Swan lamps, but, as they did not regulate very well, Mr. Raworth promised Messrs. Guion & Co., when quoting in September, 1882, for the electric lighting of the s.s. "Arizona," that means would be embodied to regulate the current according to the number of lights running. This was accomplished by adding a series winding to the shunt winding of the magnet coils, and the machines which I erected in November, 1882, on the "Arizona" (Plate XII) were, I believe, the first commercial compound-wound dynamos turned out by Messrs. Siemens Bros. & Co.

Further to economize space in engine-rooms, a method of driving the dynamo by friction was devised and used in a number of smaller steamships. The spindle of the dynamo was fitted with a pulley composed of compressed paper, and the dynamo rested in a pivoted cradle so that its pulley could be pressed firmly against the rim of the engine flywheel at its highest point.

Early in 1883 the firm with which my name is associated commenced business at Newcastle-on-Tyne, and bought a Ransome portable engine and a Siemens dynamo, and did a good deal of pioneer work to familiarize the public with the advantages of the new illuminant in the temporary lighting of bazaars, exhibitions, skating ponds and the exterior of buildings on occasions of public festivities. They also installed the electric light in many private houses, and towards the end of 1883 the late Dr. Charles Mitchell, of the firm of Sir W. G. Armstrong, Mitchell & Co., gave me the order for the lighting of his residence and picture gallery at Jesmond. The motive power was a twin-cylinder, 12-h.p. Crossley gas engine, which drove two Siemens dynamos fitted with flywheels and worked in conjunction with a set of Electric Power Storage Co.'s accumulators. The switchboard was of polished mahogany and was placed horizontally, forming a table on which were the main switches, an Ayrton & Perry ammeter and one of the first of F. V. Andersen's automatic cut-in and cut-out switches for the battery. In the centre was a rotary switch for regulating a resistance hung below the board. This resistance controlled the flow of current from the accumulator to the dynamos when the latter were used as motors for starting up the gas engine. A Cardew hot-wire voltmeter hung on the wall behind. I had an anxious time at the inauguration ceremony, as when every light was on and a large ball in progress, I received word that something was wrong in the engine-room, and on my arrival there found that the large disc flywheel on one of the dynamos had worked loose on the tapered end of the shaft and was wobbling in so ominous a manner that I, although in evening dress, had to stand over it with a long pole and steady it as best I could until we had to close down, wondering all the time what would happen if that wheel, running at 900 r.p.m., should slip off the end of the spindle.

In December, 1883, we introduced the incandescent electric light into Wallsend, when the café built by Mr. (now Sir) George B. Hunter was opened. The building was illuminated outside by alternating-current arc lamps, and inside by Swan lamps in combined gas and electric fittings. The electric current was also utilized for the simultaneous lighting of the gas sunburners in the ceiling of the concert hall, by means of small coils of platinum wire near each burner being rendered incandescent.

The generating plant in the yard at the back comprised a vertical steam boiler with engine on one bedplate, driving a Siemens dynamo for the glow lamps and a Wilde self-exciting dynamo for the arc lamps. The latter machine had two rows of electromagnets, between which the bobbins of the armature revolved. One of these bobbins supplied current for exciting the magnets, and the others supplied either alternating or direct current, depending upon the position of the brushes. This machine is now at Armstrong College, Newcastle-on-Tyne.

On the occasion of the opening of these premises an incident occurred which led me to invent the quick-break switch. The architect came to me in the course of the evening and said he did not know until then that the switches could be used in the same manner as a gas tap to lower the lights, and proceeded to demonstrate the fact. I hurriedly stopped his experiment and explained that he might easily set fire to the place through the arc that he was maintaining in the wooden switch case. The next day I conceived a plan for preventing this sort of thing, and my Patent of 14 February, 1884, was the first publication of the principle of quick-break or loose-handle construction in electric switches. Shortly afterwards I had 16 licensees manufacturing under my patent, and was awarded a bronze medal for the switches which I showed at the Inventions Exhibition, 1885.

The No. 1 "Castle" dynamo, having a single horse-shoe magnet and a Pacinotti armature, was made in 1885, and was installed at Coleraine, Ireland, in 1886, since when it has run on regular work. It is now being replaced by a more modern machine, but only because my firm are desirous of having it back to take a place of honour in our collection of antiques.

The No. 1 dynamo was followed by several machines of a 4-pole design, some of them being lap-wound and some wave-wound, but we, like other makers, were working as it were in the dark until the publication in March, 1886, of Dr. Kapp's paper on "Continuous Current Dynamo Machines," read before the Institution of Civil Engineers. This paper shed a flood of light on the design of dynamos, by showing how to calculate the reluctance of a magnetic circuit so that the field strength resulting from a given exciting power could be calculated. Since that time, dynamo design has been comparatively simple and straightforward.

DR. G. KAPP.

Members may recollect a visit paid collectively early in the 'eighties to see at Paddington Station the late Mr. Gordon's alternator used for supplying current for lighting. The machine was direct-coupled to a low-speed piston engine and appeared to us as a gigantic machine. About this period I had occasion to inspect a small lighting station in London where two belt-driven Westinghouse machines were installed. These machines had rotating armatures and in design resembled d.c. multipole machines. There was no provision for parallel running, but either machine could be put on to the external circuit and when changing over there was a momentary interruption of supply. I think that these two plants were the first practical examples of a.c. supply in this country. At that time the road of the pioneer was not smooth. First he had to battle against the prejudice of eminent mechanical engineers regarding the use of d.c. motors for driving industrial machinery, and then he had to overcome the prejudice of a good many electrical engineers, who would not hear of alternating current in any form. In fact, there were two camps in our profession. The one pinned its faith to direct current, the 3-wire system and batteries; the other, led by Ferranti, Mordey, Siemens and a few others, recognized from the first the importance of alternating current and would not admit the virtue of direct current beyond what may be called a strict "parochial" use. Especially the distrust against batteries was great in those days. I remember Mr. Mordey, after eulogizing the various advantages of alternating current, telling me that in his opinion the greatest of them was that batteries could not be used with an a.c. supply. I then agreed with him, but I see now that we were both wrong.

Although in those early days many of us became enthusiasts for alternating current, our work (except that of Dr. Ferranti) was on too modest a scale. There was some excuse for this modesty, for we were still striving after the best type of alternator. At first undue importance was attached to the problem of reducing inductance in the armature winding. This led to the design of armatures without iron cores, thus giving the additional advantage of saving iron losses, but possessing the drawback of mechanical weakness. Yet many machines of this type were built and did good service. That even a coreless armature can withstand excessive stresses I had occasion to see in the case of the single-phase Bristol electricity works, for which the late Sir William Preece and I acted as consulting engineers. The generators were Willans–Siemens sets and Mr. Faraday Proctor superintended the work on behalf of the Corporation. When I came to Bristol for a preliminary test I found Mr. Faraday Proctor in high spirits as he had that morning succeeded in paralleling the machines without any difficulty. He would show me how it was done. We carefully watched the synchronizer and closed the switch at the right moment. To our consternation there was a terrific noise and we both had the impression that the incoming machine would depart through the roof, but nothing happened. The machine fell into step immediately and continued to run quite quietly. When investigating the case we found the connections to the synchronizer reversed (this had been done by some pupils playing with them during the dinner-hour and putting them back the wrong way), so that when we switched in, the machines were dead short-circuited. Yet they stood the stress. This speaks well for the design, material and workmanship which Messrs. Siemens had put into those machines. To make sure that a similar accident should not happen again, I added to the synchronizing gear a choking coil which made the arrangement fool-proof.

In some of the early machines, notably that of Mr. Mordey, the magnetic field was produced by a single exciting coil, the object being to save copper. Mr. Charles Brown also adopted this plan as late as 1890 in his Lauffen three-phase machine, but the single exciting coil has not survived. If it is stationary there are mechanical difficulties in supporting it from the stationary and coreless armature winding; if rotating, there are difficulties in driving it and especially in preventing its twisting in the case of a sudden check in speed due to a sudden increase of torque.

In my alternator I aimed at making nearly the whole of the armature winding active, and this lead to a disc armature with a coiled-band iron core. This machine was not taken up by any English maker, but the Oerlikon Company built this machine for some years and some of them were of fairly large size, for instance the equipment of the Zurich central station worked by the water power of the Limmat. Eventually all these early machines were superseded by the type now adopted by all makers, namely, a revolving field and fixed armature with the winding housed in slots. It is curious to reflect that it has taken our profession 15 years to arrive at such a simple and straightforward design, and I cannot help speculating whether we are not at present still groping in other matters along devious paths which will ultimately lead to some simple solution. Then everybody will wonder why we did not find this solution long ago. In transformer design something similar had to be gone through. Here also we were groping. Some wanted to reduce hysteretic loss, others to save iron, others to save copper, others to reduce inductive drop, and so on, but in each case we had to pay for the attainment of our desire in some unforeseen way. In my own case I wanted to reduce labour and utilize every scrap of iron in the sheet by using the rectangle stamped out of the horse-shoe as the second yoke. The transformer proved a failure because even if tightly screwed up it acted as a trumpet. I had to abandon this apparently simple design in favour of separate sheets interleaved at the corners, which meant more labour and a slight waste of iron. Other engineers attempted absolute symmetry in three-phase transformers by a triangular disposition, but found that they had either to submit to loss through eddies at the corners where the plates crossed, or, by inserting insulation, to increase the no-load current. Eventually we discovered what things were of real importance, i.e. strong mechanical construction, interleaved joints, alloyed iron, subdivision of the winding, good insulation and efficient cooling. The highly mathematical investigation as to the best

shape and proportions of transformers undertaken by many theorists have not proved of much practical value. Makers build as it suits the workshop and, although there are considerable differences in details of design, we know quite well that all transformers made by respectable firms are about equally good.

Our original prejudice against single-phase alternating current had completely died out by 1890. In America and the Continent I do not think such a prejudice ever existed. The machines I saw in the small London station were probably Westinghouse standard machines built before 1880. In the Vienna Exhibition of 1883 Messrs. Ganz had a large exhibit of their complete system of town lighting, which was already then a standard on the Continent. Among the towns which had adopted a.c. lighting I may mention Lucerne because I had occasion later to become better acquainted with the Ganz system than is possible by merely looking at an exhibit.

To go slowly in the adoption of a new development is sometimes justified by the fear that something better may come along and then there may be premature scrapping. That is precisely what happened ; something better, viz. the three-phase system had come along, yet as far as Lucerne was concerned there was very little scrapping. The supply was at first single-phase alternating current to the large hotels along the shore of the lake, that is, over distances which could not be covered by direct current. The town grew and consequently the water power of the Reuss would not suffice, especially in winter when all Swiss rivers have less water than in summer. Meanwhile the habit of winter sports was beginning to set in and the Lucerne town council wisely resolved to make preparations for the growing demand in good time. In Engelberg there is water power which then belonged to the monks of that place and whose value was merely that of a trout stream. By the intervention of a local peasant the town was able to acquire this power at its actual value. When the purchase had been completed the engineers came on the scene and plans were worked out. The works were built and an overhead line carried to a converting and distributing station at Steghof, close to the Lucerne railway station. The old single-phase work was left undisturbed, except for branch connections to Steghof ; old customers could still be supplied by the old mains either direct from the Reuss works or through the converting machinery in Steghof, whilst new customers could get three-phase current for domestic use and power. It is interesting to note that part of the scheme was to make an artificial reservoir on the hill at the left bank of the Reuss to store pumped-up water, and thus augment the supply of power for peak loads ; a kind of Severn scheme, only with this difference, that it has some chance of being carried out at some future date.

By the time the whole profession had become reconciled to single-phase a.c. plant, American, German, Swiss and Italian makers had taken up three-phase working, but here there was some reluctance to this new development. The practicability of this system for long-distance power transmission had been demonstrated at the Frankfort exhibition in 1891, and when about this time I received instructions for preparing plans for an oversea job and to call for tenders, I found that English makers would not look at such a suggestion, whilst two continental makers were quite willing to tender and sent representatives over to ask to be allowed to tender. As it seemed to me important to get a start in polyphase work here, I tried to meet the English prejudice by admitting the alternative of two-phase current produced from two mechanically coupled single-phase machines. At last I found one firm who would undertake the work. They made a good job of it and secured repeat orders. Central station engineers had at first to order their three-phase plant from abroad, but English makers soon recognized its advantages, and now English plant is quite as good as and perhaps a little more robust than continental plant.

In the early days, to which my remarks apply, neither the art of testing nor the provision of accurately adjustable artificial loads had been brought to the present state. When the Metropolitan Company had equipped their Amberly Wharf station with some of my alternators made by the Oerlikon Company, Mr. Bailey decided to test their output in an eminently practical way. The water in the wharf was to serve as an artificial load, while the output was to be recorded by Thomson-Houston energy meters and fuel and water were to be weighed. A raft was provided with iron plates hung into the water to serve as electrodes, and warning boards were put up to prevent curious navigators from coming too near the raft. As an additional protection giving a visible indication if the system were alive, a pilot lamp was set up in the middle of the raft and this was connected to small electrodes which picked up some current out of the stream lines passing between the main electrodes. This plant worked quite satisfactorily. One rainy day a barge laden with iron pipes came along glistening with wet. I stood at the window overlooking the artificial load and was prepared to shout a warning to the bargee should curiosity take him too close to the raft. But there was no necessity. The bargee was not curious ; perhaps he had not even seen the pilot lamp. He drifted quietly to the wharf's edge and then something unexpected happened. On stepping ashore he made a big jump. I was surprised to find that he had received a shock from the stream lines at this considerable distance and at first I was also much alarmed for his safety, but I soon felt relieved because when making some remarks to me the vigour of his language showed that he had suffered no injury.

SIR JAMES KEMNAL.

A Review of the Introduction of the Babcock & Wilcox Boiler for Electricity Supply.

At the time that this Institution was called "The Society of Telegraph Engineers" the Babcock & Wilcox boiler was introduced into this country, after having been used to some appreciable extent in the United States before that time. If the path of the early days of electricity was thorny in this country, the same can be said of this boiler.

Nobody wanted the boiler when it was first offered

to the public. There had been earlier types of water-tube boilers in use in this country, notably the "Howard" and the "Root," both of which had a very inglorious record. To suggest a Babcock & Wilcox boiler in those days to anyone who wanted a boiler not infrequently met with an indication of where the door was! The boiler insurance companies were entirely sceptical of the merits of the new boiler, and none of them advised it. At that time 120 lb. per square inch was considered to be a high pressure and, as this was well within the range of ordinary boiler construction, the tendency with consulting engineers and steam users was, not unnaturally, to adhere to something familiar.

The Edison installation in Holborn-viaduct, in 1882, was the first instance of the application of the Babcock & Wilcox boiler for electricity supply purposes, and, just as electrical engineers are the most progressive and sympathetic to an innovation at the present time, so they were the first to appreciate the merit of the boiler in those days. They were generally unprejudiced. The call for resourcefulness in overcoming difficulties in their own profession elicited their sympathy with others, but in addition they recognized the advantages of higher pressures in application to their industry, and as a matter of fact higher pressures were more general in electricity plants than in any other plants for industrial purposes.

Notwithstanding the fact that the supposed disadvantages of water-tube boilers were kept steadily before the public by all the makers of shell boilers throughout the country, the Babcock & Wilcox boiler steadily made its way, and those who knew of the older types of water-tube boilers found that this particular boiler was an improvement, while the makers of shell boilers found their assertions that it was uneconomical, that it primed, and that it was not durable, entirely refuted.

The opposition was not dead, however, for not so many years later it was spoken of in Parliament by a well-known boiler expert as a "kist o' whustles." Needless to say he was a Scotsman! Others likened it to a baker's oven, but none of the opprobrium stayed its progress, for, seeing it used by electrical engineers, mining engineers, steel works engineers and water-works engineers all began to use it and to appreciate the fact that the high pressures permissible left them free to concentrate their attention on the economical utilization of the same in their engines.

Of course, the makers of the boiler applied themselves to perfecting the design, as well as to researches in connection with the use of it, so that in the course of time the cast-iron drumheads were replaced with a design in wrought steel, and the cast-iron headers made way for the steel header. The first instance of this was at the Imperial Continental Gas Association's installation in Vienna, for lighting the Royal Theatres. At that time this was a very prominent installation. It was first put up with a somewhat remarkable design of fire-tube boiler, and the combination of its remarkable features in design with remarkable innovations in manufacture caused it to last only a few weeks. I was called upon in hot haste to replace these boilers, and at that time in Austria, where there was Government supervision, no boiler that had any cast iron in its construction was allowed to be used at 10 atmospheres pressure, so the wrought-steel header (which was almost still in the experimental stage) had to be brought out of that stage and used in this installation. Those wrought-steel headers were not equal to the perfected type, but they stood well enough, and the installation was in use until the large central electric stations of Vienna—which also used the Babcock & Wilcox boiler, perfected up to date—had taken its place.

The authorities made it a condition of the order that I should superintend the erection of the first pair of these boilers, and get them passed by the inspectors, whose requirements were extremely punctilious.

Nowadays headers entirely weldless have taken the place of the wrought-steel welded header.

A subsequent event in the life of the Babcock & Wilcox business was the introduction of the superheater, 25 years ago. Mr. Babcock, of my firm in America, had previously asserted that superheating was no good! I designed it in Vienna—again for Austria—where the demand for it first appeared, as superheaters of cast iron, made by Schwoerer, had been used there and in the Mulhouse district, in textile factories. Through their use an economy up to 60 per cent had been shown on an ordinary high-pressure non-condensing engine, owing to the avoidance of condensation in the cylinder walls. Condensation was then, in engines of that type and pressure, the greatest source of waste of heat. The Schwoerer superheater at that time was generally designed as a separate installation, and was made of cast iron. The Babcock & Wilcox superheater was split up into small tubes, and was integral with the boiler. Seamless tubes were then just coming into use, and these suited the purpose admirably.

The first Babcock & Wilcox superheater installation was at that time put in a flour mill in Hungary, and is working to this day.

The first Babcock & Wilcox superheaters in this country were supplied to Messrs. Belliss & Morcom. This was very fortunate, as their engine was then beginning to be largely used for electrical purposes, and the advantages of superheating appealed to them.

The position at present is that scarcely a boiler is installed without a superheater, and pressures have in the meantime risen from 120 to 350 lb. per square inch, and even in the most modern electric stations to 475 lb.

I hear that the Allgemeine Electricitäts Gesellschaft intend to call for boilers for a working pressure of 50 atmospheres as a regular thing, in view of some advance that they have made in steam turbines. The Babcock & Wilcox boiler has been made for this pressure, so that a knowledge of what construction is required is available should this demand develop.

Another important development that I have lived through has been mechanical firing for electricity supply stations. The demand in this respect was different from that for factory work, because in the former case the load was fluctuating, and in the latter it was more or less steady. I tried almost every kind of mechanical stoker until the oldest type of all, the chain grate, was made for an installation for the City of

London Electric Light Company, at Bankside. Here an attempt was made to make the stoker meet the variable demands. In this connection I cannot say too much of the assistance and perseverance given by Mr. Frank Bailey and his staff. The stokers at Bankside were successful, and the type is now so generally adopted, with the improvements to adapt it to a larger range of fuel and to forced draught, that it needs no comment further than to say that it is more largely used for electric stations than any other type developed during the same period.

Concomitant with this has been the development of apparatus auxiliary to the mechanical stoker. Tipplers throw the truck of coal into a hopper, and conveyors take it from thence to overhead bunkers, from where it drops into the mechanical stokers. On its way it is weighed, and the ashes are also conveyed mechanically, so that developments in this direction during this period have enabled steam to be produced at a very high pressure, with a high degree of superheat, from coal that is not touched by human hands after it is put into the railway truck. In addition, the ashes are not touched by hand. That is surely a good record.

I have been invited to set forth my personal experience in guiding this work, and it is possible that it would form instructive and, in some respects, amusing reading, covering as it did endless travelling about the world, controversies in letters and papers, practical difficulties in design and construction, and, after a general acceptance of the boiler for stationary purposes, its introduction, suitably adapted, for marine purposes, but it will suffice to say that concurrently with the improvement in design and manufacture of the boiler, the firm of Babcock & Wilcox has grown, from very small beginnings, into one of the most important engineering concerns in the world, with works in which everything required for a steam plant (excepting the steam engine) is made. These works, in Great Britain alone, occupy over 100 acres.

The Company employs a clerical and engineering staff, in various parts of the world, of some 1 200 officials, and has works also in France, Germany, Spain, Japan, Italy and Australia, all of which works are engaged in similar manufactures.

DR. A. E. KENNELLY.

Electric Communication in the Year 1876.

The Society of Telegraph Engineers, later to become the Institution of Electrical Engineers, had its headquarters in the year 1876 at Broad Sanctuary, Westminster. The famous Ronalds Library, then a recent acquisition, was installed there in the Secretary's office, or the Secretary's office was installed in the Ronalds Library, according to the viewpoint of the visitor. Electric telegraphy was then mighty, both by land and sea. On the other hand, electric lighting, electric traction, electric power transmission, electric telephony and a long list of other now familiar electric activities, were non-existent. Radio communication was undreamt of.

In land telegraphy, the single-needle instrument was in very general use throughout Great Britain, along lines of railway, and on telegraph lines of light traffic. It was a sociable instrument, and it was more commonly found on way-circuits of 10 stations, than on through circuits of two. For through traffic, the Morse apparatus was in extended service ; although at that date it was the Morse inkwriter that was the familiar and cheerily clicking visitor. The Morse sounder was a rare and relatively disparaged poor relation. He left no record of his work. For Press service and congested traffic, the Wheatstone automatic Morse printer was in regular use, and also the Hughes type printer. The Wheatstone A-B-C dial telegraph, which did not call for a knowledge of the Morse alphabet, was often to be found in country districts. There was also a good system of two-wire tape-printing stock tickers installed in the city of London.

In British telegraph offices, the standard source of electric energy was the Post Office form of Daniell battery. This was a slate rectangular box, having a series of compartments, each with a porous partition. Each voltaic couple was composed of a thin copper plate and a thick zinc plate. The copper plate occupied the full width of its compartment ; but the zinc plate was narrower. The zinc plate was cast over and enclosed the end of a strip projecting from the copper plate ; so that when the couple was suspended across the wall between two adjacent compartments, the plates assumed a vertical position. The graphical representation of a voltaic battery, as then universally used in England, showed alternate thin and thick parallel lines, corresponding respectively to the copper and zinc plates of the standard Daniell battery. The disappearance of this battery, which is now probably as extinct as the dodo, has left many of our present-day electrical workers without any clear signification of the meaning originally attached to this graphic symbol of a battery, as still largely employed on diagrams ; so that we often see the thick-plate pole of the battery marked +, and the thin-plate pole — ; whereas the thick-plate pole was always the zinc or negative pole of the battery, as would have been considered self-evident at that time.

In submarine telegraphy, the long cables of 1876 were worked by Kelvin mirror receiving-instruments, with hand double-key transmitters. The young tyro cable operators were trained for several months to read mirror signals. On short cables, the left-hand beats of the spot of light, corresponding to dots, and the right-hand beats to dashes, were easy to distinguish and decipher ; but on the longer cables, having a time-constant of, say, more than 4 seconds, the retardation caused the signals to change from the staccato to the legato type, which required much more skill to decipher. Moreover, mirror-receiving of messages required the co-operation of two operators, one to call out the letters from the wanderings of the light spot, and the other to write down the message thus spelled out. The Kelvin siphon recorder was commencing to be installed.

It required to be supplied steadily with a few watts of electric power; partly to excite the ponderous electromagnets, then needed to develop the magnetic field in which the receiving coil could swing, and partly to drive the paper slip, as well as to electrify the ink. The power supply was obtained from a large tray battery of horizontal copper-sulphate cells. Each cell was about $\frac{1}{2}$ metre square, and they stood piled up, one above another, pagoda fashion, in a battery some 2 metres high. The electric motor, on top of the siphon recorder, was a simple electromagnetic rotary device, called a "mouse-mill," with a simple cam commutator. This little motor propelled the signal-recording paper tape by a vertical string drive, and also rotated a little electrostatic influence machine, for electrifying the ink-well and siphon, so that the ink was squirted on to the paper tape through the siphon, very ingeniously, in a thin line of dots, by electric repulsion. Considering that the siphon recorder had to work day and night for weeks together, it is remarkable how practical and serviceable it was. Of course it had its troubles. The electrification was often deficient in damp weather and excessive in dry; so that requests for repetition of words or messages, over the cables, were not infrequent, owing to "ink missing." From a modern view-point of electric motor design, it would seem almost impossible that the simple successive excitation and de-excitation of a fixed electromagnet, through a cam and contact, acting upon a succession of soft-iron cross-bars mounted around a wheel, could be relied upon to give such long-continued service. Fortunately, no one then knew how bad the electromagnetic design of the motor would be regarded 50 years later; so it gave relatively little trouble.

At that date, the submarine cables of the world, although much less numerous and ramified than to-day, were seldom hard pressed in carrying their traffic. Occasionally, of course, a cable might be found that worked hard, night and day; but the average cable lived a respectable citizen's life, working by day and resting by night. On night duty, the operators often had little to do, save watch for calls and occasional messages between midnight and early dawn. The leisurely inaction of those nights forms a marked contrast with modern customary submarine cable traffic. It was not infrequent for the operators at the ends of a long submarine cable, after the evening's rush was over and the circuits called each other clear, to chat together and compare notes, so as to while away the tedium of the night's vigil. In that way, trans-oceanic friendships were often formed. Thus, amusing anecdotes often circulated from cable station to cable station, and the "laugh signal" dash-dash-dot-dot-dash-dash, often went round under the seas, in the small hours.

Sir William Preece visited America in 1876 and attended the Philadelphia centennial celebration of that year, where the Bell telephone was first publicly exhibited. He brought a pair of Bell instruments back with him to London. In 1877, experimental pairs of Bell hand telephones were used over British circuits, one acting as the transmitter and the other as the receiver. Prior to that date, however, and in 1876 or 1875, the Reiss electric telephone was exhibited in London, using as a transmitter a vibrating wire and trembling contact. This earlier device transmitted music satisfactorily, but speech very poorly, and mainly by guess-work. The marvellous sensibility of the new Bell instrument for transmitting speech was soon recognized, and attempts were made to use it over submarine cables where, of course, its working range was found to be very small, and limited usually to only a few kilometres. Ever since, it has manifested a decided preference for working over rather than under the water. The telephone has recently made the human voice faintly heard across the Atlantic ocean, by radio, but not yet by cable.

MR. S. MORSE.

NOTES ON THE REMOVAL OF SOME NON-TECHNICAL DIFFICULTIES FROM THE PATH OF THE ELECTRICAL INDUSTRY.

As it is nearly 50 years since I started business life in London perhaps I may say that from the very first I have had the privilege of being intimately connected with the electrical industry. My first experience was in connection with cables through that great pioneer William Thomas Henley, who, starting as a dock labourer, was able to save enough to buy such books on magnetism and electricity as were then available and to educate himself sufficiently to carry through great electrical enterprises.

Later, through my old schoolfellow Otway Woodhouse, whose premature death was in my opinion a very great loss to the industry, I met that versatile genius (now) Sir Henry Cunynghame, K.C.B., and the late well-known telegraph engineer General Webber, a Past President of this Institution. It was through these that I came into the electric supply side of the industry and was present throughout the very important Inquiry held by Major Marindin in 1889 which settled the basis of such supply to the Metropolis.

After these few lines of reminiscence I should like to say a few words on some of the non-technical difficulties with which the industry has been confronted but which, happily, have been surmounted. When electric traction was originally proposed, committees of the two Houses had first to be taught that electricity was a possible motive power, and when that had been done at considerable cost of time and money and a start had been made by Graff Baker at Leeds, the National Telephone Company claimed a monopoly of the earth for their return currents. This claim led, amongst other unexpected results, to the virtual repeal of the provision still in force in Section 19 of the Tramways Act, 1870: "Nothing in this Act contained shall authorize any local authority to place or run carriages upon such tramway and to demand and

take tolls and charges in respect of the use of such carriages."

For the Glasgow Corporation, having obtained powers for electric traction with a clause known as the Plymouth clause protecting the National Telephone Co.'s works, called for tenders coupled with a condition requiring indemnity against claims by the Telephone Company—a condition no contractors were willing to accept—and, in consequence, the Corporation was able to induce Parliament to allow them to equip and work the trams themselves. But the telephone claims became so burdensome that Parliament was induced in 1893 to appoint a Joint Committee to deal with the matter, and their Report forms an integral part of the foundation upon which electric traction was based.

They reported (amongst other things): (1) That it was not in the public interest to insist upon electric tramways using an insulated return conductor and that such insistence would retard the development of electric traction, and (2) That it was desirable in every way to facilitate the use of complete insulated metallic returns for telephones. In addition, the Committee settled clauses for insertion in all Bills and Provisional Orders which authorize undertakers other than electric lighting undertakers to use large electric currents, authorizing such undertakers to use uninsulated returns of low resistance while requiring them to use all reasonable precautions to avoid injurious interference with telegraphic or telephonic apparatus, and they were to be deemed to take all such precautions if and so long as they employed such means of preventing injurious interference as the Board of Trade should direct. The Board of Trade in giving such directions was to have regard to the expense involved and the effect upon the commercial prospects of the undertaking.

With regard to electric lighting, under the Acts of 1882 and 1888 it will be remembered that it was the policy of the authorities to insist upon a self-contained undertaking even within a closely populated district, such as the old parish of St. Luke, Chelsea, or that of St. James, Westminster. It had been decided in 1878 that a Railway Company as a statutory body authorized to carry on a public utility undertaking was only liable for any resulting nuisance in cases where it could be shown to be the consequence of carelessness on the part of the Railway Company. But the new industry of electricity supply, in addition to being made subject to many other onerous conditions, was also made liable for nuisance even if it could not carry out its statutory obligations without creating a nuisance.

Ferranti tried to meet that difficulty by his great scheme for a station at Deptford for a London electricity supply, but it was long before justice was done in this matter to the industry, and it came about in a curious way. In 1897 the Chelsea Company had been driven to seek another site for its generating station than the one set aside by Lord Cadogan when planning the rebuilding of his Chelsea estate, for the Board of Trade—the authority entrusted with the power to grant statutory authority for electricity supply—was not authorized to grant any powers to purchase lands by compulsion.

The Chelsea Company found a new site and was able to secure by private purchase the freehold interest and all other interests in it save one, a leasehold of some 9 years unexpired, the acquisition of which was essential to the Company. The owner absolutely refused to sell unless the Company bought at the same time for some £30 000 adjoining property they did not want. The Company therefore went to Parliament and, as new privileges were involved, Parliament sent the Bill and some others to a Joint Committee presided over by Lord Cross, whose report forms a very important part of the foundation upon which the electricity supply industry has since become firmly established. For not only was it then laid down that electricity undertakings might be given compulsory powers to acquire land but that where this was done the liability for nuisance should be the same as in the case of railways, i.e. only when carelessness was proved.

Ler me here add one word on another very important aspect of the electricity supply industry. After the passing of the Act of 1882 many undertakings were started but, in consequence of its very onerous conditions, the necessary capital was not forthcoming and in London only one company undertaking, the Chelsea Electric Supply Co., and one municipal undertaking, that of St. Pancras Vestry, survived. Even after the Act of 1888 was passed and the Marindin inquiry held it was not easy to obtain the necessary funds. I am not exaggerating at all when I say that in this respect as well as in many others the industry owes a great deal to the initiative, foresight and courage shown by Mr. Garcke and his great supporter the late Mr. George Herring, in relation to the financial requirements of the industry—as a result of which confidence was established in electrical securities.

I should not like to pass by the Electricity Supply Act without referring to the great work done for the industry by Sir Harry Renwick when the Bill of 1919 was before Parliament, but for which electrical undertakers would have been compelled to sell their generating stations and main transmission lines upon most inequitable terms, to mention one matter only.

I have referred only briefly to the way in which some non-technical difficulties have been surmounted and it is perhaps unnecessary to say that a very great deal had to be done first to bring home to Ministerial and Parliamentary bodies on each occasion the need for amelioration and so induce them to appoint Committees to deal with the matters in question, and secondly, to get together the necessary evidence and arguments to satisfy the Tribunal appointed as to the existence and extent of the evil and to point out how it might be met.

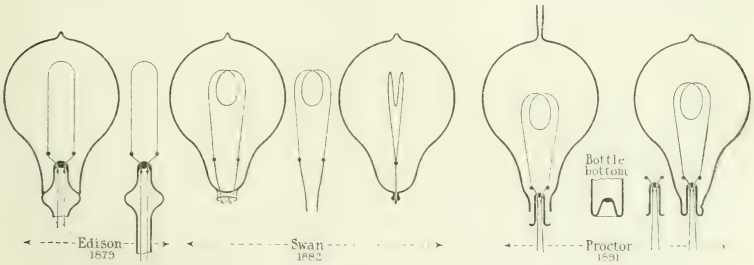
We now have a Commission of experts specially appointed to deal with all such matters and it is only necessary to bring any difficulty to the notice of the Commissioners to ensure a patient and sympathetic hearing.

MR. C. FARADAY PROCTOR.

In 1878 I made what I believe to be the first lamp-holder for an incandescent electric lamp, namely, the first Swan lamp, which consisted of an elongated bulb with platinum leading-in wires, one at each end, and, I might almost say, the world-famed "carbon rod."

In 1880 I made a life test of Swan lamps with filaments manufactured from parchmentized cotton threads with thickened ends. Current was supplied by a Gramme dynamo and a group of Swan accumulators in parallel with the lamps to steady the circuit.

I mention these details because an exactly similar temporary installation was fitted up in a small printing works close to the Literary and Philosophical Society's rooms on the occasion of a lecture given by Swan about that date. The dynamo was driven by the same steam engine which drove the printing machinery, and the current was carried over the street by cables kindly lent us by Mr. A. W. Heaviside of the Newcastle-on-Tyne post office.



I had not been very long in charge—the other assistants had gone across to the lecture hall—when the engine driver came to me and inquired whether it was possible that my machine was preventing his engine from stopping. He had shut off the steam at the stop-valve and at the boiler, and his mate had gone for a plank to chock the flywheel, but by that time a messenger had arrived from the hall saying that the lights had gone dull. That, I think, must have been one of the first cases of a printing works being driven electrically by current obtained from accumulators.

In 1882 James Swinburne and I were in Paris making incandescent lamps. One evening he was explaining to me the relative merits of a series-wound Gramme and a shunt-wound Siemens dynamo, when he suddenly realized that it should be possible to combine the two systems of winding so as to give a constant voltage independent of the load, in other words a system of compound winding. Almost at the same instant, however, he remembered that Brush had devised something similar, not as a compound winding, but as a teaser current (as he called it) to prevent change of polarity in the case of a generator for electroplating work, and Swinburne felt that this would make it impossible for him to patent a compound winding.

About this time I came into possession of a fine sample of coppered Edison lamp which not only exhibited the characteristic green of a thin copper film but also showed that the deposit—probably due to a short-circuit between the terminals—was not of a powdery nature but had in parts peeled off the bulb, showing that the film of copper had an appreciable tensile strength, and suggesting the possibility of making thin sheets of metal in this manner.

In 1884 I had to investigate what appeared to be a case of the careless use of dirty platinum wires in certain lamps, but which proved after investigation to be a case of the decomposition of the lead glass of the lamp bulb. In the process of exhaustion the glass gets very hot and becomes a conductor, and we were getting lead deposited on the one pole and gas liberated at the other.

Early in 1891 I devised a new method of constructing incandescent electric lamps, which has been so universally adopted that I think a description may be of interest. I should mention that there were two strong reasons for an improved design.

First, the Swan design was bad, both mechanically and electrically. The only adhesion between the cap and the lamp was that due to the plaster in the cap sticking to the thin piece of glass through which the leading-in wires pass; this strained the weakest part of the lamp, and also lowered the insulation resistance of the lamp by reason of the plaster coming into contact with the conductors. In the alternative Edison design the glass work was of a very costly description needing highly skilled workers.

The second point of serious concern was the cost of platinum which, owing to a ring formed in England, raised our cost to 3d. per lamp.

One day while sitting on the terrace at Vincennes overlooking the Marne it occurred to me that the

bottom of an ordinary beer or soda-water bottle exactly fulfilled the requirements of an almost perfect design for a lamp end; the cylindrical end would exactly fit the vitrite cap, the recessed bottom would enable the use of short platinum wires through the glass and ordinary copper wires down to the cap, also the wires would be prevented from coming into contact with the plaster, and the insulation resistance of the lamp would be improved. The only remaining problem was how to hold a funnel-shaped piece of glass with a filament attached to it, while it was being fused on to the tubular part of the bulb. While this improvement was being developed we were also experimenting on making lamps by machinery. At first the lamp was held horizontally—as is the usual custom for hand-made lamps—but it at once became obvious that by adopting a vertical position the funnel-shaped stem would stand on a tubular holder, gravity being sufficient to hold it on, and the bulb could be lowered over it. I have gone into this matter in some detail, but when it is remembered that the average number of lamps sealed in per man per day at about this date was 60 to 80, whereas a good operator can now seal by machinery about 1 000 lamps per day, the advance will be seen to be considerable, quite apart from the better mechanical design. Sketches of the three types of lamps are here reproduced (see page 479).

The next step of importance was the improved bayonet lamp-holder with the well-known **S** insulator, which was patented in 1895. The fact that we should have been so long content with the old form shows the difficulty of getting out of a rut, or of keeping our brains alive to defects and methods of improvement.

The great epoch-making discovery of the metal-filament lamp I shall leave to others to describe; it deserves a paper to itself. That we are drawing wires of tungsten of a diameter less than 1/1 000th of an inch through diamond dies and in lengths of several thousand yards, is in itself a marvel of mechanical skill.

There is just one other point that I think is worth noting. Edison in his tar-paste filament patent recommended the winding of filaments in close coils so that each convolution would assist in heating the next. In the modern half-watt or high-efficiency lamp the essence of the invention is the close winding of the coils, not so much for mutual heating as for mutual protection.

Mr. H. W. RAVENSHAW.

EXPERIENCES OF AN ENGINEER IN CONNECTION WITH ELECTRICITY IN MINES.

From 1876 to 1880 I served a pupilage on the Great Western Railway, finishing with a most enjoyable year of firing on the locomotives.

I afterwards "learnt" electricity at a school of telegraphy. In 1884 I went to Messrs. Edmunds & Co. as an instrument maker and draughtsman and on 19th June went to their works at Halifax, and my diary shows that on 21st June my pay was raised to 35s. a week. The manager had come from Manchester and had a great store of drawings and windings for "A," "AA" and "B" Gramme dynamos. The "A" Gramme was the only machine that was of any use; it gave 30 amperes at 50 volts.

We also made Hochhausen arc lighters with ventilated commutators and automatic regulation which rocked the brushes.

By April 1885 the firm had become Messrs. Goolden and Trotter. Mr. A. P. Trotter introduced to us the Gravet slide rule. I had used a slide rule in 1881, a Routledge, but the brass slide fell 100 feet from the top of a blast furnace.

We then went ahead at a great rate, for, though we early designers were pygmies according to modern ideas, what we lacked in knowledge we made up by enormous enthusiasm, and we generally worked at least one 24-hour spell every week. Magnetic circuits were beginning to be understood and Hopkinson's and Ewing's papers brought a great deal of light on the subject. I find in my 1886 notes a calculation for a "saturation curve with external resistance of air," and from then onwards nearly 20 note-books are full of amazing calculations of lemmas, magnetic leakages, armature fields, and sparking coefficients. We certainly rushed in where the present-day angel would fear to tread. As a matter of fact, we generally got good results although the dynamos, and motors took some very original shapes.

Up to 1887 we were making dynamos for the Admiralty of 3·6, 8 and 16 kilowatts, good little undertype machines for Heenan & Froude spherical engines. We were quite up to date in that we were always late in delivery, and if a machine was not quite right on test, windings were cut out and left with insulated ends. I had a very bad time some years later in trying to explain to a Naval Officer at Portsmouth the reason for some "dead" coils on a dynamo which had been returned for repair from the West Indies.

By 1887 we had made shunt-wound self-regulating arc lighters, and a train-lighting set with automatic regulating and reversal gear.

My first reference to motors for mining was in the middle of 1887, a coal-cutter with 12-inch armature. Mr. Ll. B. Atkinson had, I think, a hand in it as I find rather a good portrait of him as a callow youth in a note-book of about that date. Early in 1888 a 12-h.p. coal-cutter motor was in hand for 250 volts, 700 r.p.m. It was series-wound and was supplied by a series-wound dynamo which gave 300 volts. These pairs of series-wound dynamos and motors worked very well. The speed of the motor was self-regulating and we afterwards supplied a number of them for pumping in mines.

In 1888 I tried some mild steel castings for field magnets and found them to be quite satisfactory, although the castings varied in permeability. It was found that, owing to the large hysteresis loop, series motors could be built which did not run up to an excessive speed when the load was removed.

By this time we had also built smooth-core bar-wound drum-armature dynamos for the Navy, driven by Willans engines, which ran very well and were highly efficient.

About this time our works were moved to Woodfield-road, London, and I had the great advantage of carrying out a number of tests at Messrs. Willans & Robinson's works at Thames Ditton and of knowing that great engineer, Peter Willans.

From 1889 onwards, mining machinery was in regular demand and we built motors and dynamos in considerable numbers for coal-cutting, haulage, both continuous and main and tail, pumping and winding. We built quite a number of 100-b.h.p. haulages, a size which is frequently put down at the present day. The pressure was usually 350 volts for small plants and 550 to 600 volts for the larger ones, all direct current.

In 1891 we built some 1 000-volt d.c. dynamos and motors with drum-wound armatures, and a number of 1 500-volt Gramme sets of about 100 kW output, two in series, giving 3 000 volts total. These machines with Gramme armatures gave a great deal of trouble, partly due to the great heating of the armature shafts owing to eddy currents set up by the armature field. We also had a good deal of trouble which was traced to hysteresis losses in the armature core owing to ageing after excessive heating. Totally enclosed motors ran well on the test-plate and overheated very badly on regular load. The Gramme armatures worked with very heavy densities in their armature cores. A good deal of trouble was also caused by the use of cast double helical gears for the first reduction.

We had by 1892 developed a fine class of starting, regulating and double-pole switch for 500 volts (d.c.). They were in circular boxes with wide machined flanges and were at least as good as and, in my opinion, probably better than any modern flame-tight switch of the present day. The connections were not brought through glands but were made to substantial terminals on the outside of the box, all intermediate connections being bedded in bitumen. Unfortunately, prices were badly cut and, after overcoming all our difficulties, the firm repeated history and failed.

In 1896 I took up consulting work and was responsible for a new plant at the Manvers Main Colliery. This consisted of an E.C.C. dynamo and two 50-h.p. haulage motors by Messrs. Crompton, about a mile in-bye. These motors were of the undertype and of a considerable height with bar drum armatures, and were totally enclosed in large boxes of $\frac{1}{4}$-inch steel plate. There were two manholes near the brush holders. They drove main and tail haulages which required reversal of the motors, an unusual arrangement, and regularly worked up to 75 b.h.p. One motor ran without the cover being removed for 7 years and was only opened out on the disconnection of a shunt wire. They were taken out of the pit after over 20 years' service in 1920 as they were replaced by compressed-air motors, it not being thought advisable to have electricity away from the pit bottom. They will probably be put to work again on the surface.

Crompton motors seem to have very long lives, as I know of two motors at least 25 years old which are still at work driving pumps underground.

In 1901 the late Mr. David Davy, who was chairman of both the Hickleton & Manvers Main Collieries, asked me to design the 225-b.h.p. motors for the main haulages at both collieries. These motors were made by Messrs. Greenwood & Batley and had the Mordey chord winding on the armatures. Those at Manvers Main are still at work and I inspected them a short time ago. They are perfectly sparkless from quarter to full load, but spark rather badly on no load. They drive continuous haulages through belting, so that they never reach the sparking limit. They have no interpoles and have very little copper on the fields.

A 350-kW exhaust-steam turbine was installed at Hickleton Main Colliery in 1906 with a steam accumulator, and a second mixed-pressure set of 500 kW was shortly afterwards put in. The d.c. plant was afterwards changed to 3 000 volts (a.c.) in 1911.

Up to about 1900 almost all mining plants were on the d.c. system and there appeared to be an idea that three-phase motors could not be started on load.

Many of the generating plants were of a very unreliable character, quite large dynamos being driven through belting by old winding engines which governed very badly.

The advent of the exhaust and mixed-pressure turbine was a great stride in advance of old methods and three-phase plants (which have a great many advantages over d.c. sets) have been put down in large numbers.

Three-phase plant has not, however, entirely replaced direct current, as there are several plants at work at the present day having very large numbers (in one case over a hundred) of d.c. motors in use underground.

The tendency at the present time appears to be to put down very large steam winding engines and to use the exhaust steam to supply turbines which either drive alternators or geared reciprocating air compressors.

Where possible, collieries are being linked together by 10 000-volt lines, this being a great advantage at nights and week-ends and saving great expense in the provision of spare plant. Personally I belong to the school which considers that electricity should not be used beyond the shaft pillar. This means in most cases that the main haulages and pumps are driven electrically and compressed air is used in-bye.

I have for many years tried to impress on the authorities the importance of using lead seals on the cases of all switches and enclosed motors underground, so that they can be opened only by authorized persons who can be identified. This system has been adopted at more than one colliery and in my opinion should be enforced by the Home Office.

Many ventilating fans are now driven by self-starting synchronous motors. Mr. L. Hunt, who has done some fine work in that branch, was a Goolden pupil in 1890.

It is somewhat remarkable that our profession is not a dangerous one. In 45 years of regular work I have never met with a serious accident, although in the early 'nineties the principal members of our Goolden staff were nearly wiped out by a burst steam pipe and again by a burst gear wheel.

I wonder how many electrical engineers all over the world remember "Old Bill Hay," the foreman, running 100 yards (according to his evidence in a court of law) in 7 seconds to turn off the steam valve

DR. A. RUSSELL.

I have been asked to write something about my early experiences of electrical engineering. Unfortunately I had little to do with electrical engineering prior to the founding of Faraday House in 1889. I have pleasure, however, in writing a few reminiscences of my experiences of electrical testing which date back about thirty years and my recollections of some of the early pioneers of the electrical industry. Thirty years ago many inventors devoted a great deal of attention to primary batteries, to thermo-electric piles and to methods of converting coal directly into electricity. Most of them knew little about the theoretical side of the subject. A very common error was to think that the output of a primary or thermo-electric battery was the product of the open circuit volts and the short-circuit amperes. Having thus overestimated the output by at least 400 per cent it was not surprising that the companies floated to manufacture the batteries came to grief. Claims were also made that various types of reflectors and diffusers increased the total amount of light coming from a luminous source. As a rule the proof was based on the fact that by their use the area of the vertical candle-power curve was appreciably increased, the assumption being made that the candle-power of the source was proportional to this area. It was necessary to point out to them that on their assumption it would be better simply to use a similar lamp taking double the electrical power, as this would quadruple the area of the candle-power curve. In these days a very large number of experiments were made to determine the value of the Parliamentary Standard Candle. It then dawned on us that as the barometric height and the humidity of the atmosphere were not mentioned there was no such unit. We found the German Reichsanstalt most helpful in maintaining our photometric standards. The value of their Hefner unit was practically constant. In 1894 we took the English candle to be 1·14 Hefners, but later on, in 1900, we changed it to 1·12 Hefners. This value of the English candle agrees closely with that adopted in 1909 for the international candle, namely, 1·11 Hefners.

The Thomson balances which we used to measure currents in 1890 have now been in daily use for 32 years and are still as good as when they were new. Our voltages we got from Clark cells which we made ourselves and which were tested by the Board of Trade Laboratory. The older types of meter sometimes rotated forwards on no load and sometimes backwards on a condenser load. The measurement of inductances with a secohmmeter we did not find satisfactory and we had no confidence in the formulæ then given for computing inductances. The measurement of alternating power on low power factors was perhaps the most difficult problem with which we had to deal. The invention of accurate wattmeters has greatly simplified the work of a modern test-room. In the old days also the methods of getting the wave-shape were so laborious that they were seldom used.

In 1889 Sir William Thomson gave his second Presidential Address to the Institution. It was entitled, "Ether, Electricity and Ponderable Matter." The address enabled many to realize how important the solutions of certain physical and mathematical problems were in helping the development of practical engineering. He described the "skin effect" in conductors, but I do not think that he was aware that the problem had been worked out by Oliver Heaviside in the *Electrician* some five years previously. On reading his Address again I find that he refers in very appreciative terms to much of Heaviside's work. His ber and bei functions are identical with the functions which Heaviside denoted by M and N. Thomson's ber was a contraction for "Bessel real" and his bei was a contraction for "Bessel imaginary." Using similar contractions some years later I called the functions which have to be taken into account when considering the return current the ker and the kei functions, ker being a contraction for Kelvin real.

I was in Sir William Thomson's class at Glasgow University in 1879 and again in 1882. Although he was busily employed at that period in considering electrical engineering problems, the subjects on which he lectured had little connection with electricity. His reminiscences of Helmholtz, Regnault and Green carried us back to a previous generation and gave us a very vivid insight into the knowledge and ideas of the physicists of the early half of the nineteenth century. Many of us regret that the name under which William Thomson did his best work should have become lost in a title. Although we now generally talk of Kelvin balances, yet we always talk of the Thomson effect. It seems a pity that his name, whether Thomson or Kelvin, has not been associated with some fundamental unit. The kilowatt-hour is sometimes called the Kelvin, but as the primary unit of energy is the Joule, and there seems to be no reason for associating two names with energy, the nomenclature is not a happy one. His name, however, must always be associated with the absolute thermodynamic scale of thermometry. It is one of the eight names—*nomina clara et venerabilia*—which we commemorate on the walls of our lecture theatre. We might now with advantage consider the advisability of extending this list. Amongst the older generation of electricians the names of Gauss, Green and Hertz suggest themselves, and there are many of a later date whom electricians delight to honour.

In 1892 Oliver Heaviside published his "Electrical Papers" in two volumes. They considerably advanced our knowledge of electrical theory. In particular his theory of a "distortionless" circuit was profoundly suggestive. Pupin and others successfully applied his theories to practice. Far reaching developments in long distance telephony were the result, and both the industry and the community benefited largely by Heaviside's labours. It would have been a great boon to all of us if his proofs had been less condensed, but it is quite possible that if they had been written in full they might never have been published. Referees are often autocratic and sometimes they are wrong. Anyhow, authors who have had papers turned down

can take heart from Heaviside's experiences. Oliver Heaviside was once a member of our Council and contributed several important papers to our *Journal*. One of these, "On Induction between Parallel Wires," published in vol. 9, p. 427, of the *Journal*, is of value at the present time as it explains the *modus operandi* of the action which takes place between power distribution lines and telephone lines.

In 1889 I met Lord Crawford and Robert Hammond, two of the founders of Faraday House. Lord Crawford was one of the founders of our Institution. He told me how anxious he was in the early days that Sir William Thomson should become President of the Institution and how pleased he was when this occurred in 1874. Lord Crawford's laboratory was at 48 Greek-street, Soho, and it was in this laboratory that the first Conversazione of the Institution was held. In conjunction with Cromwell and Alfred Varley he made researches on the phenomena of electro-magnetism and carried out many tests on various types of storage batteries. I remember him as one of the kindest of men, always ready to give a helping hand to any struggling inventor. In these early days the energy of Robert Hammond was almost unbelievable. He did an immense amount of work in extending the use of the electric light both in this country and in Spain. His house at Highgate was one of the first in Europe to be electrically lighted throughout. Apart from his volcanic energy, what always impressed me most was his marvellous arithmetical powers, and the uncanny way he could detect errors in lengthy reports almost at a glance.

The loss of Silvanus Thompson and Duddell during the war was a most grievous blow to the industry, but their work lives and will continue to live. The discoveries of J. J. Thomson, Rutherford and Bragg have opened up new and fascinating fields of exploration for electricians. The efficiency of glow lamps is still far from the theoretical maximum.

Many of us remember the astonishment with which we heard of X-rays and radio-telegraphy, and the incredulity with which the atomic theory of electricity was first received. Seeing the advances that have been made in our electrical knowledge and its practical applications during the past 50 years we can look forward to the future with every confidence. We believe that the rate of progress of our knowledge in the coming years will be at least as great as in the past, and that discoveries will be made not less wonderful than those whose birth it has been our privilege to watch.

MR. H. M. SAYERS.

To-day's Debt to the Founders of The Institution.

Fifty years is a long time in the working life of an individual and it is not surprising that there are now but two survivors of the founders of this Institution, the original members of the Society of Telegraph Engineers.

In addition to the flux of time, there are some special reasons which tend to obscure the part played by those founders and their colleagues in the history of electrical science and electrical development. Within 10 years of the foundation of the Society electrical engineering developed in quite new directions, and these rapidly attained a magnitude and commercial importance which left telegraphy a comparatively small branch of applied electricity. This was a result of the entry of the dynamo and the electric light into the field of practical use. In many respects this amounted to a discontinuity. Particularly it brought into electrical work many engineers and others whose previous work involved little knowledge of electrical science. These soon outnumbered the telegraph engineers. For a variety of reasons not many telegraph men went into the new branch. Further, the new developments required the solution of new problems, especially those relating to dynamo design, the control of large currents and pressures, system efficiency, and alternating currents, which had not been before telegraph engineers.

It is easy to understand that the pioneers of heavy electrical engineering who had to solve these problems, most of them not previously familiar with electrical work, are a little inclined to magnify the work of their own generation, and to diminish that done by their forerunners. It is an effect of mental perspective. It is seemly at this Commemoration to recognize that electrical engineering did not begin about 1880, and to put on formal record some of the material which the "heavy" electrical engineers found available for their work, in the shape of knowledge acquired largely by telegraph men, foundations of electrical science laid in the main because of the commercial and social values of the telegraph.

In the first place, the fundamentals of exact electrical measurement had been defined. This, as is well known, had been done by a Committee of the British Association which had worked out two systems of electrical units, based on the C.G.S. and decimal systems. They had determined the dimensions and values not only of the "absolute" units, but also of practical multiples and sub-multiples of these. They had given names to the most important of the electromagnetic series—the ohm, the volt, the farad—and had made material standards of the ohm and the microfarad, as well as investigations which enabled anyone to set up practical standards of electromotive force. It may be remembered that the Clark standard cell was described in the year 1876, so that a portable material standard of voltage was available from that date, but, even before that, standard cells, usually some form of Daniel, were in use by telegraph engineers.

So the heavy electrical engineers about 1880 came into the heritage of a scientifically defined system of electrical units, convenient for calculations and commercial uses, with material standards available and methods of measurement very fully worked out.

Telegraph engineers had long before abandoned the use of such indefinite units of resistance as a "mile of telegraph wire," and knew the voltage of the various kinds of batteries they were using. It may be news to

many members that before 1880 the Post Office telegraph engineers measured received currents, and specified the working currents of receiving apparatus, in milliamperes. It may be that they called them "milliwebers." The ampere was not internationally recognized as the name of the practical unit of current until 1886, but the word was certainly in use, and displaced "weber" in this country some years earlier. Fleeming Jenkin in his "Electricity and Magnetism," fifth edition, dated 1880, defines the practical unit of current as "farads * per second," with a footnote to the effect that "Mr. Latimer Clark calls it a weber." The writer is under the impression that "ampere" was even then in more general use. The name is not important, the unit of current was one of those defined and in practical use.

Telegraph engineers then had in use precise and practical methods of measurement of the quantities with which they were chiefly concerned. These quantities were mainly conductor and insulation resistance, capacity, and voltage. The most precise work was that done in the testing of submarine cables, which were under almost continuous test during manufacture and laying. These tests included the use of pressures up to 300 volts, which was as many times the working voltage as the high pressure tests now made on transmission cables, a larger ratio in fact than is now applied to extra-high-pressure cables.

R. S. Culley's "Handbook of Practical Telegraphy," sixth edition, dated 1874, which is before the writer, gives diagrams and directions for cable testing which show that this work was done in a thoroughly precise and scientific manner. It was well said about that time that the electrical science of the telegraph engineer was far more scientific than the electrical science taught in the universities. The book quoted shows that telegraph engineers knew how to arrange their batteries on scientific principles, and that they were not under any false impressions as to the relation of internal resistance and electromotive force in batteries. Culley mentions the "common battery" system as then in use in various places, and points out that low-internal-resistance batteries are alone suitable for such use. He also points out that on leaky circuits it is better to decrease battery resistance by using larger cells, or by putting sets in parallel, than to increase the number of cells in series, giving numerical examples. Culley gives the B.A. Committee's definitions of the ohm, volt, and farad, and uses those terms. He was the first Chief Engineer of the Post Office Telegraphs, and an original member of the Council of the Society.

The two books already mentioned, together with the early editions of Kempe's "Handbook of Electrical Testing," will amply prove to anyone interested in this subject that the heavy electrical engineers had available to them a most valuable knowledge of practical scientific electrical measurement. It is quite true that many of the early workers in electricity supply and so forth, failed to take advantage of this knowledge and suffered for their oversight.

* Farad is defined as the quantity contained in one farad capacity charged to one volt, with the remark that it seems unnecessary to give it a special name. It was, however, given the name "coulomb" very soon after the date of the book.

One extremely important piece of work which the "heavy" men found done for them was the investigation of the effect of impurities on the conductivity of copper, and the prevalence of specifications and methods of manufacture and test which ensured the use of copper of high conductivity. This work was done in the interests of submarine telegraphy. It has been of far greater money value to the heavy electrical industry. In part return, the heavy industry, by making electrolytic refinement a commercial process, has brought about a decided improvement in the conductivity of copper.

The telegraph engineers had also done useful work in investigating the magnetic properties of iron and steel in their various forms.

Another hardly less important piece of work had systematized the theoretical and practical mechanics of overhead lines. It is hardly too much to say that everything of importance in the design and construction of overhead lines was worked out by the telegraph engineers. They had also determined that well-vitrified porcelain made the best insulators for such lines, and had settled the best forms for insulators and methods of testing them.

The localization of faults in lines had been brought to a high degree of precision.

This is an incomplete statement of the spade work which the heavy electrical engineer found done for him. It was collectively of very great value and must not be forgotten.

Though not a great many telegraph men came into the heavy work, there were some who made their mark. Among these were Webber, Cardew, Ayrton (who was trained for the Indian Telegraph Service), Bright, C. W. Siemens, Mordey, John Hesketh, while Arthur Wright and R. Wallis-Jones came straight from the old Hanover-square School of Telegraphy. Edison was a telegraph man in his early days, and had distinguished himself by telegraphic inventions before he started in electric lighting. No doubt others whom the writer has forgotten or never knew of should be added to this list. The authors of one of the earliest and most popular handbooks of electrical engineering, Slingo and Brooker, were both Post Office telegraph men, the former completing his service as Chief Engineer, and now holding a very important post in South America. One ought not to omit the name of Wm. Langdon (one of the original members of the Society) who carried out much electric lighting and power work on the Midland Railway, and read a paper before the Institution on the electrification of railways, remarkable for its prophetic character; or Preece, who did a good deal for electric lighting even before he retired from the Post Office.

Then there are the cable makers. The older firms turned their knowledge, experience and works, on to the heavy cable work with great readiness and enterprise Without those resources the early work of electricity supply would have been very difficult. Even to-day cables insulated with some of the materials used for submarine work cannot be surpassed for certain locations.

To a considerable extent the same thing is true of the instrument makers. The instruments, apparatus, standards and methods for accurate measurement and

calibration were there, at least for direct-current work. The application of them to the very different requirements of heavy electrical engineering has been a work of time, but the principles have not varied much. All the moving-coil instruments of to-day are direct descendants of the Thomson siphon-recorder movement. The principles of the potentiometer and the shunted ammeter were in use for telegraphic measurements. The Weber dynamometer and the quadrant electrometer are still basic instruments for standardization work.

It is hardly necessary to mention that Kelvin, Fleeming Jenkin, and even Maxwell and Heaviside, did much of their electrical work in the interests of telegraphy.

The writer has been moved to pen these notes because he was himself in the Post Office Telegraph service seven years before he went into electric lighting in 1881. He found the electrical knowledge obtained in that service of the greatest use in his new sphere, and, knowing some of the founders of the Institution, can testify personally to the high quality of their work and their characters. Knowing personally something of what present electrical engineering owes to the older men, he feels that it is only just to remind the younger generation of its debt to the forerunners of applied electrical science in telegraphy; men who were, for the most part, earnest workers, singularly silent about their own achievements, and who should not be forgotten.

It was not the least of their accomplishments that they founded the Society of Telegraph Engineers and, when the newer work developed, they welcomed the workers into the Society, giving them the benefits of a ready-made organization, which has been of inestimable utility to the science and the arts depending on it.

MR. A. SIEMENS.

Electrical Instruments and Measurements.

When I first came to Messrs. Siemens Brothers' Works at Woolwich in July 1867, the chief electrician was occupied with the adjustment of a "resistance measurer" (described in the *Philosophical Magazine*, 1867, vol. 34, p. 270) intended to provide a means of measuring electric resistances in a simpler way than that required either by a differential galvanometer or by a Wheatstone bridge.

Two equal and parallel coils were fixed upon a sliding bar guided by rollers, and moved in the direction of its length by contact with a curved surface, pressing against one end of the bar and capable of being moved at right angles to the bar in the same horizontal plane. Between the coils a magnetic needle was suspended in a fixed place, so that the distance between the two coils and the needle was varied, in opposite senses, when the sliding bar was moved. The electric current from the battery divided into two branches, one passing through one coil and a known resistance, and the other through the other coil and the unknown resistance. The movement of the curved surface, altering the position of the sliding bar and the coils, was measured on a scale, giving the value of the "unknown" resistance when the needle was at zero. Once the curved surface was made, the instrument functioned correctly and in a reliable manner, but the curve had to be made empirically in the first instance, and the then available resources were not sufficient to devise a commercial method of reproducing the curve; hence this method had to be scrapped. This proved to be a valuable lesson, as it showed that scientific deductions may be correct but cannot always be carried out.

In the instrument shop at Woolwich the first dynamo-electric machine made at the works with double **T** armature was used to magnetize the steel magnets of telegraph instruments, but was not available for running uninterruptedly for any length of time, because the armature became too hot.

Not very long afterwards dynamo-exploders were constructed, in addition to magneto-exploders, and both types are still manufactured at Woolwich.

My next encounter with measurements was at Berlin, where I attended lectures at the University in 1868, and where I watched in the laboratory of Siemens and Halske the reproduction of Werner Siemens' mercury unit, which, in the same year, was made the legal unit of telegraphy by the Vienna International Telegraph Conference.

Incidentally I desire to call attention to the fact that nowadays the international unit of resistance is a definite length of a column of mercury, not differing greatly from the "Siemens unit"; it should not be forgotten, however, that Dr. Werner Siemens and the various firms with which he was connected were among the first to adopt the "international units" for all their measurements.

Later on in the same year I was assisting in erecting part of the Indo-European telegraph line in Persia, and we used magneto-electric machines for testing every evening the insulation of the circuits completed during the day. For this purpose the far end, or rather the commencement of the line, was insulated at prearranged times, and naturally the capacity of the completed circuits increased daily. One evening at testing time, when a great number of natives had gathered round, it was explained to them that the line discriminated between friends and strangers, by allowing friends to touch it with impunity while strangers would receive a shock. As a proof, I went up the ladder and touched the line (which had been earthed at our end) without anything happening; then one of the natives went up the ladder, touched the line and promptly fell down, greatly frightened, as he had received a severe shock, the result of a thunderstorm in the hills through which the line passed, and of the severing of the earth connection while the man went up the ladder.

At that time there were no proper roads and practically no tilling of the land between towns in Persia, so the line was kept straight as long as this was possible. Naturally the caravans very soon adopted the telegraph line as their "direction" posts, and we were reproached afterwards that we had built the line in

the middle of the road instead of at the side. As a remedy against collisions between loads and posts, each post was surrounded by a cone of earth about 5 ft. high, which effectually kept horses and camels at a safe distance. I mention this because the same measures were adopted later on in the Sudan to protect telegraph posts from damage by hippopotami.

In the following year I was transferred to the Caucasian part of the work, to the section on the Eastern shore of the Black Sea, where a cable was laid to avoid the spurs of the Caucasus that here reached the sea. This cable consisted of three copper conductors insulated with gutta-percha served with jute and covered with copper strips wound helically on it. This construction was adopted so as to have a very light cable easily handled in laying and easily lifted for repairs. It turned out, however, that it was a hopeless task to keep a cable laid parallel to the shore from being broken by the debris, brought down from the mountains by the rivers, and pushed gradually forward into deep water. A land line had eventually to be constructed under great difficulties, which crossed the rivers by very long spans, and the cable has been abandoned.

I returned to England in 1871 and for about three years assisted Sir William Siemens in his "furnace" business, when I had an opportunity of studying his electrical pyrometer, described in Volume 3 (1874) of our *Journal*.

About 1873, Messrs. Siemens Brothers introduced their universal galvanometer, which served for three purposes: (1) To measure resistances; (2) to compare E.M.F.'s; (3) to measure currents.

In September 1875 I joined the cable s.s. "Faraday" on a repairing expedition, remaining with the ship at Halifax, Nova Scotia, until 1877. During part of the time I made observations with Sir William Siemens's "bathometer" (*Philosophical Transactions of the Royal Society*, 1876, p. 671), which worked quite well so long as the ship did not roll too much, but unfortunately the "pumping" of the indicator in bad weather prevented reliable readings being taken when they were most wanted.

I may mention here a contrivance, which was introduced some time later, to enable the engineer at the brake of the paying-out drum to regulate the percentage of slack of the cable without knowing the depth of the sea.

For this purpose a pianoforte wire is paid out at the same time as the cable, but quite independent of it, and with so much retarding strain that it lies on the bottom of the sea without any slack. In other words, the length of the track of the cable is measured by the length of wire paid out.

The revolution counters of the cable drum and of the wire drum are mechanically connected by gear wheels so as to show the percentage of slack on a dial visible to the engineer at the brake, whose task it is to keep the percentage of slack at a prearranged figure.

This he does by varying the retarding strain on the cable, which as a maximum should not exceed the weight of a length of cable, hanging vertically from the ship to the bottom of the sea, such a retarding strain having the effect that the cable is paid out without slack.

The retarding strain is recorded automatically by the mechanism moving the indicator of the dial; consequently, as long as the engineer keeps the percentage of slack constant, the curve recording the retarding strain represents the depths of water where the cable touches the bottom of the ocean.

The use of the additional wire laid without slack is mentioned in the monthly report of the Berlin Academy of Sciences, 17th December, 1874, in a communication from Dr. Werner Siemens, but the details of the apparatus as used on board the s.s. "Faraday" were designed by Mr. G. S. Grimston.

The provisional specification 3 317/78 of Dr. Obach's tangent galvanometer with movable ring was never completed. It was similar to the Siemens and Halske tangent galvanometer introduced in 1859, but by moving the ring its sensibility could be varied so that strong currents could be measured direct without shunting them. As currents can be measured, either by the tangent of the angle of deflection or by the cosecant of the angle of inclination of the movable ring, when the angle of deflection is kept constant the instrument can be used to check its own readings.

In spite of these advantages, the instrument has dropped out of use; and it has been replaced by cheaper contrivances; for instance, by the dynamometers first suggested by Professor Weber of Göttingen in 1839, in which the current traversed a fixed coil and a coil suspended by a torsion spring, the latter being turned until the swinging coil returned to its zero position. These again have been superseded because the deflections were proportionate to the square of the current, so that tables had to be used in connection with them.

With regard to the legislative aspect of the early development of the electrical industry, I think that I cannot do better than repeat part of my Presidential Address of 1894, which refers to the Electric Lighting Act of 1882.

It was found that, excepting the Corporation of the City of London, there existed no authority in the United Kingdom that could permit the laying of underground mains, and that a special Act of Parliament was requisite.

To the unsophisticated mind this appeared to be extremely simple, as all that was needed was to extend the powers of the various authorities to whose care the laying of water and gas pipes and of telegraph lines was entrusted, so that they could deal in a similar manner with electricity mains.

Some of the electric light companies were of opinion, however, that the same object would be attained if they received powers from Parliament to make agreements with the local authorities, subject in every case to the approval of the Board of Trade, for establishing a system for distributing electrical energy in the various districts; and in pursuance of this policy several private Bills were filed for the session of 1882.

The Government of the day did not consider it to be of public advantage that a limited number of electric light companies should have such roving

powers, and a general Bill was therefore introduced with the intention of facilitating and expediting the general application of electricity. With this object in view, powers were to be given under the Bill to the Board of Trade to grant Licences or Provisional Orders to electric light companies.

The Licence to establish a system of electrical distribution in any district was to be granted to an electrical company who had succeeded in gaining the consent of the local authority; and its conditions were to be settled between the local authority and the company, subject to some general provisions to be drawn up by the Board of Trade, and subject to the sanction of the Board of Trade.

In districts where the local authority objected, the electric light company should, nevertheless, be able to establish itself by means of a Provisional Order of the Board of Trade; but to obtain this the company had to prove that the majority of the inhabitants of the district desired to have facilities for obtaining electrical energy.

It will be observed that in this draft the Licence was intended to be the usual way of obtaining power to lay underground mains, and the formalities for settling it were extremely simple; the Provisional Order, on the other hand, was to be resorted to in exceptional cases as a means of overcoming the objection of local authorities. This is confirmed by the fact that in the draft the duration of the Licence and of the Provisional Order were equal.

Curiously enough, nobody during the passing of the Act, or afterwards, seemed to care much about the fate of the licensing system, which was completely stripped of its importance, and alluded to by the learned counsel on both sides as suitable only for experimental purposes. Following up this train of ideas, the duration of a Licence was curtailed to seven years. Had the intention of the Government, however, been carried out as at first designed, we should now enjoy in the United Kingdom the same facilities for establishing electric supply systems that have aided the development of the electrical industries so much in other countries, instead of being obliged to apply to Parliament in each separate instance, at great trouble and expense.

Seven years later the system of granting powers by way of a Licence was practically dropped altogether, and since then the Board of Trade has declared its intention not to grant Provisional Orders to electric light companies unless they have obtained the consent of the local authority, thereby abandoning entirely the original object of the Provisional Orders.

The ultimate result of all this legislation has therefore been to create a number of difficulties in the establishment of distributing systems in the United Kingdom; in fact, the formalities of applying for a Provisional Order are very similar to those required for a private Bill, so that practically we are not in a very much better position than before the passing of the Electric Lighting Act of 1882.

In 1876 Sir William Siemens visited the Niagara Falls, and suggested in the following year in his Presidential Address to the Iron and Steel Institute at Newcastle-on-Tyne a scheme for transmitting power, developed at the Falls, to Buffalo and even to New York by means of electricity.

About the same time Lord Armstrong utilized a small waterfall at his country house to transmit power and light, and Sir William Siemens did the same at Tunbridge Wells.

A more ambitious scheme was the lighting of the Royal Albert Docks to enable ships to manipulate their cargoes at night, and by similar means the promenade at Blackpool was lighted.

In 1879 the reading room of the British Museum was lighted by arc lamps, whose steadiness was ensured by absorbing 25 per cent of the voltage by the resistance of the leads, a lesson learned at the Albert Hall, where the arc lights would not keep steady but contributed their share to the concerts.

About the same time Messrs. Siemens Brothers made an agreement with the town of Godalming to light all its streets by means of electric lamps, and also to supply glow lamps for house lighting at a fixed price per annum, the power being obtained from a waterwheel and the distribution effected by overhead wires. Unfortunately the water power was too variable, so that eventually steam power had to be substituted, and then the town would not take over the plant. All the same, Godalming was the first town in the world to have all its streets lighted by electricity, all gas and oil lamps having been replaced by electric lamps during the two or three years that the plant was in use.

A similar agreement with Hull under a private Act obtained by the town was also terminated, but in that case the electric lighting was eventually carried out by Messrs. Siemens Brothers in accordance with a further agreement.

I will just mention Sir William Siemens's experiments on the influence of electric light on plants, which he has described in a paper read before the Institution. His suggestion to utilize electricity for metallurgical processes led to experiments with electric furnaces, at first carried out for him by Dr. Ferranti, and then taken up, after Sir William's death, by Professor Huntingdon of King's College.

Shortly before his death, Sir William was present at the opening of the Portrush–Bushmills Electric Tramway, the first of its kind in the United Kingdom, which had been built under the direction of Mr. William Traill, assisted, as far as the electric equipment is concerned, by Dr. Edward Hopkinson, who was at that time employed in the Electric Light and Power Department of Messrs. Siemens Brothers & Co.

Up to the end of 1884, Messrs. Siemens Brothers had laid six cables across the Atlantic for various companies. Thousands of miles of telegraph lines had been constructed by them in almost all the countries of the world and fitted with suitable instruments.

A "lock and block" system of railway signals was being developed, and all the problems of telephony soon presented themselves for study and solution.

In short, the application of electricity developed in so many ways that commercial undertakings had to begin to specialize, or at least to give up the

ambition of carrying out all possible applications of electricity.

Under such circumstances, the further development became an international task, which is still being carried out, but it ceases to be a reminiscence of an individual.

MR. DANE SINCLAIR.

EXPERIENCES OVER FIFTY YEARS OF A TELEGRAPH AND TELEPHONE ENGINEER.

In visualizing the position, one question of interest would surely be: "How many of those in the industry as engineers or electricians when the Institution was formed, are still alive, and of that number, how many are still at work?" I am one of the latter number, and I hope that some means will be found of getting out such a list before the proposed Commemoration Number of the *Journal* is issued.

To those of us who are not particularly gifted with a very retentive memory, or the pen of a ready writer, much that would be interesting and instructive now, is gone for ever; but the following few instances that remain in my memory, either point to a moral or tell a tale.

One of the earliest jobs in which I was interested was the fitting up with electric communication, from each compartment to the driver and guard, of the Queen's train, in 1871. The flexible connection between the carriages—the plug and socket (later called plug and "jack")—how interesting it was to me, being the first I had seen, and how I examined and studied each detail and part of them in my room during evening hours, are points as fresh in my mind now as if they had occurred only yesterday. I wonder now whether it was my good fairy, or some prophetic instinct, that riveted my attention upon these same plugs and jacks so long before their use in telephone work proved how much they were to be employed. I have now been intimately connected with them for over twenty years, as a buyer and user, and for over twenty years as a manufacturer, during which time millions have passed under my supervision. How many millions in all have been put into use by the telephone industry of the world is one of those calculations I prefer to leave to someone else, remarking only that at the time I have spoken of anyone who dared to state the extent to which that class of article would during the working years of a lifetime come into use would have been considered as heading straight for a lunatic asylum.

The next milestone that claims attention was the invention of the "Bell" telephone receiver, when at the Philadelphia Exhibition of 1876, Lord Kelvin (then Sir William Thomson) made known to all that human speech could be conveyed along a wire. The effect upon the then ordinary telegraph engineer was simply staggering. The news, coming from such a source, had to be taken seriously, and I set to work (one of many others) to prove it and to see if I could make a telephone.

The technical journals, giving a somewhat meagre description of the telephone, reached me while I was engaged in Japan in the construction of telegraph lines, and had finished the laying of a deep-sea cable between the island of Shikoku and the mainland. Consequently the materials at my disposal for making a telephone receiver were quite insignificant, but I was in possession of a Morse telegraph relay instrument, and this I dismantled, and from the relay coils took the necessary silk-covered wire. With this, in connection with a soft rod of iron some four inches in length, and an ordinary cotton bobbin (or reel), on which I wound the silk-covered wire, I soon constructed the internal part of the receiver. Having no machinery with which to make a screw of any kind, the difficulty was to get at the regulation necessary as between the diaphragm of the receiver and the pole-piece of the internal part of the telephone, and this difficulty was overcome as follows: I had an empty coffee tin, measuring about six inches deep and about two-and-a-half inches across. This I filled nearly full with boiled sweet potatoes, into which I immersed the centre part of the telephone, and pressed it down until the pole-piece was just parallel with the top; and upon this I placed the lid of the coffee can, to act as a diaphragm, making two holes in the can through which to lead the wires out. Such was my first telephone.

I made two of these in less than forty-eight hours from the time of receiving the technical journals, and on the following day I tried speaking results on six hundred yards of ordinary telegraph wire. This experiment was quite satisfactory, as speech was conveyed to and fro with the greatest of ease. I then telegraphed to a European friend to come to the mainland end of the deep-sea cable on the following evening, and I sent one of the receivers over to him, with a note asking him to disconnect the land line from the deep-sea cable after working hours and endeavour to speak to me at a specified time. With these two receivers, conversations passed very freely and distinctly on this seven miles of deep-sea cable, without any difficulty: we spoke, we read passages of printed matter, we exchanged whistling tunes, and to some extent we tried singing, all of which was quite successful.

After returning from Japan in 1879, I joined the National Telephone Co. as District Engineer at Glasgow, in 1881, by which time telephone exchanges had been established in the principal cities and towns in this and other countries.

The question of way leaves was,in those days, all-absorbing. Subscribers desired telephones, but there was no legal power under which wires could be erected, but leave from owners of property for every fixture, pole or wire, had to be obtained, and "for ways that were dark, and tricks that were vain," that work was certainly peculiar. No permission could be obtained either to fix upon or cross over a certain block of buildings in Glasgow. Every means was tried unsuccessfully to get permission: I interviewed the owner, and when he had threatened me with all the pains and penalties of the law if I dared either to fix on or cross his property

by wires, I simply replied that the public wished the services, and it was my duty to erect the wires. At the early hour of five next morning, a kite, with its string, was across his property. To the kite string a wire was attached and drawn over: with this wire two more wires were drawn over, to form an endless loop, and in this way, before 9 a.m. twenty wires were across and fixed. The owner of the property, being a "sport," called at my office during the forenoon, and insisted upon shaking hands with me, and added, "You will have no further trouble from me."

A second case necessitated using the roof of a bank. Every legitimate means failed, owing to the power and determination of the bank manager. But the wayleave must be got. How? Inquiry revealed that the manager had a daughter who liked to go to private dances. The most likely young man in my service was asked to get at the father through the daughter, and he took on the duty only after I agreed to pay his bill for a new evening dress suit. This I did, and about six weeks later the young man proudly walked into my room with the usual wayleave form duly signed by the bank manager; and for many years, if not up to the present day, a standard—carrying several hundred wires—has been witness to Cupid's powers where all others had failed.

The telephone had not long been invented when it was seen that the receiver, as a transmitting device, was not good enough for public service, and a transmitter with induction coil was added, with improved results. Carbon in many different forms was tried, and, in granulated form, continues to give the best speaking results. Practice led to a difference of opinion as to whether it was better to have the transmitter fixed, so that the user must always go right up to it to speak, or to have the receiver and transmitter combined attached to a flexible cord, for the greater convenience of the user. This question is still unsettled—some countries favour one form and some the other. In this country the hand combination form has disappeared, although at one time it was largely in use: I consider its disappearance to be a great disadvantage to subscribers.

For two or three years after the commencement of the telephone, iron line wire was used, but when the first trunk lines between towns proved it unsuitable for long-distance work, copper for the long-distance work, and light bronze wire for town and city work, became general—and continue so, except that at the present time underground cables for local, as well as for long-distance trunk work, are much more used.

In the early 'eighties, the work done by the late Professor Hughes was so important as to mark a very distinct improvement in telephonic matters generally for ever after the appearance of his two papers read before the Society of Telegraph Engineers. The Professor's work educated ordinary telephone and telegraph engineers for the first time into seeing the great difference there was between dealing with high-frequency currents such as exist in the telephone circuit, and dealing with the electric current used before that date for telegraphic purposes. This knowledge, coupled with the information he gave with regard to conductors generally, actually revolutionized both the engineers' ideas and the equipment in telephone exchanges and telephone work generally.

I think I cannot better explain the position at that time than by repeating what the late Sir William Preece said in the final discussion on Professor Hughes's paper:

"I do not suppose that we have ever had a paper brought before us that has formed such food for thought and possessed such elements for discussion as that read by Professor Hughes. The paper has a peculiar merit in that it has brought to the knowledge of the many, that which necessarily was possessed previously by but a few.

"I do not know any theory, not even Clerk Maxwell's theory, that would have predicated what we have seen brought before our Society. There is nobody who has placed in the hands of us practical men such a splendid apparatus, such useful tools, with which to peer into the internals of matter as Professor Hughes has done, not only in this paper, but in other papers that we have listened to with so much pleasure and delight."

The next important step in the advance of telephony that commenced its career in the 'eighties, was the idea of working telephone exchanges automatically, i.e. having a public exchange service without any telephone operator. I believe that the first exchange of this class (although of only a modified form) was invented and put to work by me at Coatbridge, near Glasgow, in 1886. That was in the days of earth-circuit lines, and the automatic switchboard was then built to work on these lines; but when, shortly after this date, all authorities decided that metallic circuits were necessary to give a good service, this automatic equipment—born, perhaps, before its time—died out, and was never again taken up.

In later years, however, the question of automatic exchanges was pushed forward in America, as the result of very excellent inventive work done by Strowger, and these exchanges showed good practical results from 1896 onwards. In 1898 several exchanges were at work, giving excellent service; and at that date I, personally, was absolutely convinced that automatic telephone exchanges had come to stay, and ever since I have been a warm advocate of their introduction, under all circumstances. It is now, therefore, pleasant to record that over one million telephone subscribers' lines are in regular service; and to-day, the rate at which automatic equipment is being built, especially in America, Australia and Canada, exceeds the anticipations of even the best wishers of automatics.

From the time when the telephone exchange industry first started, until after 1910, many unsuccessful attempts were made to find a telephonic relay to act for long-distance telephone work, in the same way as the relay had acted previously for long-distance telegraph work, and the want of such a relay had a very retarding effect upon the introduction and use of long-distance telephony, because the limit of speech—especially on an underground cable—did not much exceed 200 miles, even with the best cables. Now, however, due to the excellent work done by Professor Fleming and others in connection

with the telephone relay, or repeater (known in practice as the "Thermionic Valve"), the telephone engineer, having at his disposal an actual telephone relay, can construct working lines up to any distance without any difficulty. Certainly, within the distance covered by any continent or country, the work should be comparatively easy, whether it is 500 or 5 000 miles.

In general I would remark that the position of the engineering authority responsible for the working of a telephone system in any great city or area throughout the world, has not always been a comfortable one. I can safely say that, throughout a very long experience in this business, I hardly ever met an ordinary telephone subscriber—whatever the class of his business may have been—who did not know better how to run a telephone exchange business than the individual charged with that duty. As a consequence, I found serious complaints against the telephone service to exist in London, Paris, Berlin, Stockholm and other cities on the Continent, as well as in New York, Chicago, San Francisco and other great American cities. It was the universal privilege—and, I might say, practice—of telephone subscribers generally throughout the world to grumble and write complaints to the Press. Once, whilst on a visit to the manager of the telephones at San Francisco, I overheard the Mayor of that city, who had been visiting London, tell the management at San Francisco that, after the excellent service he had had in London, it was evident to him that they (in San Francisco) knew nothing about running the telephone exchange business properly. Of course, I know sufficient to be sure that the ordinary Englishman would reverse this and say that there is always a good service in every country except his own. For many years Sweden was held up to the telephone engineers of the world as a sort of Utopia, where all was satisfactory from the telephone point of view, but I have a very lively recollection of seeing the local newspapers in Stockholm castigating the management of telephones there to perhaps a greater extent than I had ever known in any other city.

The fundamental cause of all this commotion of complaint about their service that has gone on for so many years, was primarily the fact that, for every telephone call made, there were in connection with it (on a non-automatic exchange) two members of the public, and one expert operator in between, and the latter was, of course, always blamed for all mistakes, which ninety-nine times out of a hundred originated with the subscriber himself. He, as a result of giving a wrong number, was put on to a man he did not want—it was, of course, the fault of the operator, and never that of himself; and hence the rush to write a complaint either to the telephone authorities or to the Press, or both.

One of the points much in favour of automatics as against the use of operators, is that, for such mistakes as a user makes, he has nobody but himself to blame, because if he gets a wrong number he must know that he has not used his "dial" correctly.

These complaints have always existed in telephone work, and presumably will continue to exist for a long time to come: but how best to overcome troubles of this kind is always the first duty of all honest telephone engineers; and from my long and intimate knowledge of them as a class, I have not the slightest hesitation in saying that they have all served their day and generation well.

MR. G. SUTTON.

ELECTRIC CABLES, 1872 TO 1922.

The history of 50 years' development of electric cables is similar to that of the Institution itself, for as the Institution of Electrical Engineers, covering all the numerous phases of electrical work, had its origin in the Society of Telegraph Engineers, so the different types of cable used in the many branches of the industry for various pressures and currents may be said to have been evolved from the simple insulated conductor used 50 years ago for electric telegraphy. In the Presidential Address at the first meeting of the Society, considerable reference was made to the problems of line conductors and insulation, and some of the problems mentioned there are still before us to-day.

At a very early date copper had been selected as the most generally suitable conductor. Previous to the 'sixties the variable conductivity was a serious difficulty, but about that date the labours of Matthiessen produced a uniform standard of purity and conductivity. Subsequently the electrolytic process of copper refining rendered comparatively easy and certain the uniform production of material of the desired standards.

The only other material that has challenged the position of copper is aluminium, which in 1872 was a rare and costly metal, but which has of recent years been produced on a large scale at a price that brings it within range. Although possessing certain attractive properties its use for cables has been limited, chiefly on account of its greater bulk.

The primary form of conductor, viz. a simple circular wire, is still the best on electrical grounds, but other considerations, mainly mechanical, have demanded a departure. Evolution took place through certain stages of twisting 3 or 4 wires together, grouping a larger number in a rope formation, stranding concentric layers, or building multiple conductors of a special shape to economize the enveloping dielectric and protective materials. The building-up of conductors of a considerable sectional area by the use of a large number of small wires has in recent years been replaced by a more enlightened policy of selecting larger initial wires. Bare conductors, apart from aerial lines, have had only a brief and chequered existence, and it was early proved that conductors must have a continuous covering of some dielectric or insulating material. These have been subject to far greater changes than conductors, and some materials and methods that were unknown in 1872 have since emerged. At that time gutta-percha (G.P.) had proved its worth for submarine telegraph

cables, and was also used for underground telegraph wires and for railway signal work. For submarine work it is still supreme, but it has been almost abandoned for underground telegraphy, and its use on railways is limited. It was used to some extent in the early days for telephone cables, but by 1900 was entirely superseded.

Indiarubber was well known and used 50 years ago, and this dielectric has survived to a very considerable extent. It received a front place as an insulator for house wiring in the early days of electric lighting, and it has with slight modifications retained its position to the present day. Enormous quantities of rubber-insulated house wires are used annually, and there seems little prospect of its being superseded for this purpose.

With the growth of electric lighting systems requiring feeders and distributors with heavier conductors, rubber was naturally used also, and large quantities of rubber cables were laid down by distributing companies. The more strenuous conditions of public supply and higher pressures, together with consideration of cost, etc., induced users and makers to look in other directions, and the discovery of other materials as dielectrics led to the practical abandonment of rubber for main cables. The most noticeable feature is that whereas 50 years ago the raw rubber was wild or native Para rubber exclusively, to-day large quantities of cultivated or plantation rubber are used. Although a reference to the files of the Patent Office shows that numerous inventors have proposed the use of all kinds of gums and compounds, scarcely any have proved their suitability in practice.

The use of vulcanized bitumen for underground cables followed. Very considerable quantities were used, notably the first underground system of electric light cables for the City of London, but the use of bitumen is now practically confined to mines, where a great deal is still used.

Upwards of 30 years ago layers of jute or hemp yarns impregnated with oil were tried in conjunction with a lead sheath. This system proved fairly satisfactory for the low pressures then prevailing, but it was found unsuitable for the higher pressures adopted at a later date.

The need for a better method of insulating underground cables became urgent and was met by the introduction of manilla and other strong papers impregnated with resinous oils and lead-sheathed, which to-day forms the standard dielectric material for such cables. In its dry state, for the production of air-space cables, it has enabled telephony and telegraphy to be attained by underground distribution over long distances which had hitherto been impossible. It may be noted that the use of paper as an insulator for high-pressure power cables owes much to the initiative of Ferranti in his Deptford scheme. The dry-core paper cables for telephony originated in the United States, but possibly reached their present perfection by developments in this country.

Gutta-percha and rubber, being relatively impervious to water, did not in the early days of the industry require any protection, except such as was necessary to preserve them from mechanical injury, in which case the protection was usually in the form of steel wires. Although known to early submarine engineers as a sheathing it is now generally referred to as an armouring. With the more strenuous conditions of development of electric light and power distribution, it was found desirable and even necessary to enclose rubber cables in a seamless sheath, and with the hygroscopic or fibrous dielectric alluded to above such a sheath is imperative. I believe that the Silvertown Company was responsible for the production of the first lead-sheathed rubber cable.

Lead sheathing was patented by W. F. Cooke in 1838 to 1846, but it did not come into practical use to any extent until about 1880. The permanence of lead is well known, and this lead sheath represents a distinct advance. The cost of lead had no bearing on the electrical industry 50 years ago, but to-day it is a controlling factor. It is impossible to imagine what would be the position of the industry to-day without lead, seeing that whole telegraphic and telephone systems of the United Kingdom, and also the major part of the bluk power-supply systems, depend upon it.

The protection against mechanical damage, i.e. armouring, has in one sense not materially altered from the form adopted by the early submarine engineers of the 'sixties. Round wires of steel laid in long spirals round the cable are still used, although special shaped wires are occasionally employed. A cheaper form of armouring, viz. ribbons or tapes of steel wrapped round in short spirals (known as steel-tape armouring) has been used to a considerable extent. This form, although unsuitable for submarine work, having little resistance to longitudinal stress, has proved suitable for certain power and lighting work.

The protection of unarmoured cables by embedding them in cases or troughs filled with bituminous material, or by drawing them into ducts, had, and still has, a considerable vogue, and the latter method is a standard for telephone work. It is worthy of note that the recent practice of some very large power companies is a reversion to earlier practice, that is, burying suitably armoured cables direct in the ground.

Makers of cables have always appreciated the advantages of standardization without imposing rigid limits in restraint of improvement. In 1899 they co-operated with the Institution, through the Cable-Makers' Association, in preparing a report in which part of Matthiessen's laboratory work on copper was presented in a unified and practical form. They also introduced standard sections of conductors in 1900, and standard thicknesses of dielectric, lead sheath and armouring, and certain tests for power cables in 1903.

The report and standards were adopted without appreciable alteration in 1904 by the Engineering Standards Committee, and form the basis of the present B.E.S.A. standards for cables, which find general acceptance in most English-speaking countries.

In common with other branches of the industry the design, construction and use of cables have been to some extent governed by Parliamentary legislation and the consequent regulations of Government Departments, as well as the requirements of municipal and other local authorities. It must, however, be conceded that the departmental requirements have been chiefly of a general character, specifying certain results to be obtained

and the details of methods of compliance except for certain cases have been left to the maker or user.

Board of Trade Regulations under the Act of 1898 were designed to protect the public safety and prevent interference with the State telegraphs. Tests of dielectric strength were prescribed and were readily met by the makers of cables. The earlier regulations did not anticipate a pressure higher than 3 000 volts, but special Regulations for extra high pressures were made in 1908, and to-day many miles of cable are working at 30 000 volts.

Requirements of the Department to ensure no unsafe rise of pressure in the ground or on other circuits by reason of a fault to an extra-high-pressure main resulted in the conductivity of the lead sheath being increased by copper strips or steel wires, which are frequently referred to as B.O.T. sheath. More modern developments provide for such protection by automatic switching gear which permits of a reversion to a simpler cable in most cases.

Between 1888 and 1904 the size of cables was somewhat limited by the regulations which fixed at 300 kW the maximum to be carried by any feeder, but after the later date the restriction was removed. To-day a single feeder sometimes carries as much as 12 000 kW.

Regulations of the Home Office under the Factory and Workshop Act, 1901, did not require any radical departure from the general trend of development. In the field of mining, however, legislation has had a direct bearing on cables. Doubtless the early installation of electricity in mines was subject to some abuse, and the conditions underground demanded special attention. The earlier code of regulations under the Coal Mines Regulation Act, 1889, was superseded by comprehensive special rules in 1912, and these, under the far-reaching Coal Mines Act of 1911, became the General Regulations now governing the use of electricity in mines. Some departures from the usual practice in cable manufacture, however, met the regulations, and it is a matter for congratulation that the number of accidents in mines, due to the failure of electric cables, is extremely small.

MR. A. A. CAMPBELL SWINTON, F.R.S.

Some Early Electrical Reminiscences.

The earliest electrical event that I can remember was the taking over of the telegraphs by the Post Office. The official date of the transfer was 5th February, 1870, and it must have been about this time that the change was brought to my notice by seeing the erection, along the roadside, of the wires connecting the Post Office of our Berwickshire county town to the railway station, where the telegraph office had previously been located.

One cannot but wonder whether, if this earliest effort of nationalization had not been effected and the telegraphs had been left to development by private enterprise, as they have been in the United States of America, it would not have been better for the country, particularly as in that case the telephones would no doubt also have remained in private hands.

A few years later came, in 1875–77, Alexander Graham Bell's wonderful invention of the speaking telephone, closely followed by T. A. Edison's carbon transmitter and phonograph, and David Hughes's microphone. It must be difficult for those who do not personally remember the enormous public interest that this series of inventions aroused, to realize how great this was, being only equalled, in my experience, by the sensation made in 1896 by Röntgen's discovery of the X-rays.

I have never ceased to marvel that Bell's original arrangement, in which, as will be remembered, the same instrument, one at each end of the line, served in turn both as transmitter and receiver, worked as well as it did. The speech was wonderfully articulate, and with the larger forms of instrument very fairly loud over short lines. For instance, with a pair I made and set up between two houses some 400 yards apart, about the year 1878, speech could be heard several yards away from the receiver. Indeed, we used to call up simply by shouting into the instruments, which had 6-inch compound horse-shoe magnets, and diaphragms about 4 inches in diameter, with deeply coned mouthpieces.

Considerable controversy arose over the invention of the microphone, Edison accusing Hughes of having stolen the idea from his carbon transmitter. No doubt the two intruments had much in common, and Edison was undoubtedly the first in the field. But it is fairly clear from Edison's specifications that he misconceived the manner of operation of his own instrument, thinking that the resistance of his carbon button varied under pressure throughout its mass, while Hughes put the whole theory of these instruments on a sure foundation by pointing out that the action was due to variations in the contact resistance between the conducting parts. It would also appear from Hughes's notebooks, to be referred to presently, which contain a diary describing his experiments on the microphone, with rough illustrations of his instruments, that his was quite an independent investigation.

It is interesting to note that none of these remarkable inventors had received anything of the nature of what we should now call a scientific education. Hughes was originally a professor of music, but, prior to bringing out the microphone, had achieved fame and fortune with his type-printing telegraph, even now still in considerable use. Edison was, to begin with, a railway newsboy, practically self-taught, while Bell, whose telephone invention was of a fundamental type, was a teacher of the deaf and dumb. Even to-day Prof. Bell does not pretend to be an electrician; indeed, a few years ago he remarked to me that he was told by his friends that he could not be one, as otherwise he would have known beforehand that his telephone would never work. In this connection it may be mentioned that Hunnings, who first invented the modification of the telephone transmitter with carbon granules, which

was the forerunner of all the modern transmitters used in practice, was a clergyman of the Church of England living in the neighbourhood of Darlington. He also was scientifically untaught.

It has now been known for some years that though he published nothing at the time, Hughes, in the years 1879–80, was experimenting with what was in fact a form of wireless telegraphy. Hughes died in 1900, and his widow, who was an American, returned on his death to the United States. Recently, Mrs. Hughes died, bequeathing to the British Museum a number of her husband's notebooks. A few months ago the Keeper of the Manuscripts at the Museum asked me to examine these notebooks with a view to deciding whether they were of sufficient interest for the Museum to accept the bequest. The notes, some of which are in ink and some in pencil, mostly presumably in Hughes's own handwriting, are in parts very difficult to decipher and still more difficult to understand, as Hughes seldom called things by their right names, and the notes were evidently intended for his own personal use and not to explain matters to others. It is, however, clear from them that during the years 1879–80 Hughes made numerous and successful experiments in the transmission of signals across space by means of the radiation given off by what he calls the extra current from a small spark coil, using for reception a Bell telephone and battery connected in a separate receiving circuit, including sometimes a microphone, which apparently acted as a coherer, or sometimes a very delicate thermo-couple, which seems to have played the part of rectifier. He began with transmissions across his sitting-room, then from one room to another in his residence, then from the latter down the street, along which he walked with the apparatus in his pockets and the telephone to his ear. He evidently received signals over considerable distances up to several hundreds of yards, and even tried the effect over half a mile, though here he got no very definite results. He sometimes earthed one or both of his transmitting and receiving circuits, thereby getting enhanced effects. He notes with evident surprise that the addition of an iron core to his extra-current coil, which increased the visual intensity of the spark, instead of increasing the strength of the transmission, as he expected, stopped it completely, no doubt owing to the core diminishing the abruptness of the spark or the frequency of oscillation below what was requisite.

It must be remembered that this was long before either Lodge's or Marconi's experiments, and, indeed, some eight or nine years before Hertz's memorable discoveries. Hughes seems to have had no conception that he was dealing with electromagnetic waves. He was, however, very sure that his effects were not due to ordinary electromagnetic induction, and seems to have thought that they were to be explained by electric conduction through the air, expressing astonishment that the results could be obtained through so great a resistance.

The following extract from one of his notebooks is a very human document and one of somewhat tragic interest, as it marks the final close of his experiments on this particular line. He was evidently so disheartened by the criticism he received that he entirely dropped this line of investigation. The notebooks continue for several more years, but the matters referred to relate to quite different lines of research.

"February 20th, 1880. Mr. Spottiswoode, President of the Royal Society, Prof. Stokes and Prof. Huxley, visited me to-day at half-past 3 p.m. and remained until quarter to 6 p.m., in order to witness my experiments with the Extra Current Thermopile, etc. The experiments were quite successful, and at first they were astonished at the results, but at 5 p.m. Prof. Stokes commenced maintaining that the results were not due to conduction but to induction, and that results then were not so remarkable, as he could imagine rapid changes of electric tension by induction. Although I showed several experiments which pointed conclusively to its being conduction, he would not listen, but rather pooh-poohed all the results from that moment. This unpleasant discussion was then kept up by him, the others following his suit, until they hardly paid any attention to the experiments, even to the one working through gaspipe in Portland-street to Langham-place on roof. They did not sincerely compliment me at the end on results, seeming all to being very much displeased, because I would not give at once my Thermopile to the Royal Society so that others could make their results. I told them that when Prof. Hughes made an instrument of research, it was for Prof. Hughes's researches and no one else. They left very coldly and with none of the enthusiasm with which they commenced the experiments. I am sorry at these results of so much labour, but cannot help it."

Signed D. E. Hughes.

"February 21st. I wrote to Mr. Spottiswoode, that my opinion, firmly based on true experiments, that it was conduction and nothing else; so I have made matters worse, and may expect nothing more from them, except that they will probably copy my apparatus and make their own experiments. Adieu."

Hughes was no doubt quite wrong in ascribing his effects to conduction through the air, but the pity is that he got the impression that his results were not as novel or as remarkable as he had himself thought, and as indeed they were, with the consequence that he did not pursue his investigations. Had he done so, with his great experimental skill and untiring assiduity he would doubtless have got a great deal further. The correct theory would have come afterwards, as has happened in other similar cases.

Though it is much to be regretted that the pursuit of these experiments, which might well have accelerated the advent of practical wireless telegraphy by some 16 years, was abandoned, it must not be supposed that Hughes's merits were not really appreciated even by those whom he mentions above as critical. Written across the page of the notebook containing the extract I have quoted, are the words, "June 7th, 1880, was made a Fellow of the Royal Society." Now, not only, as mentioned, was Mr. Spottiswoode President of the Royal Society at the time, but Prof. Stokes and Prof. Huxley were the two Secretaries, and members of the

Council. Although elections to the Royal Society were then not formally made and announced till June, it was about the preceding month of February that the Council met and decided upon its recommendations as to new Fellows. It would appear, therefore, that just about the time of the visit of the President and the two others that Hughes records above, the Council containing these gentlemen was selecting him for recommendation as a Fellow.*

In 1881 the Electrical Exhibition was held in Paris, at which were gathered together, for the first time, a most comprehensive selection of all the wonderful electrical inventions of the preceding years. There were, of course, telephones of all the improved forms that had been developed from Bell's, Edison's, and Hughes's discoveries, and also the dynamos of Pacinotti, Gramme, Siemens, Edison, and countless others. Arc lamps there were galore, including the famous Jablochkoff candles with which the Avenue de l'Opéra and, afterwards, the Thames Embankment were lighted. Indeed, at that time no electrical inventor seems to have considered his position complete unless he had at least one new form of arc lamp to his credit. The first electric tramway ever installed, constructed by the firm of Siemens & Halske, ran to the Exhibition in the Champs Elysées from the Place de la Concorde, while for the first time there were shown in competition the then newly invented incandescent lamps of Swan, Edison, Lane Fox and Maxim, together with a vast array of switches, fuses, cut-outs, and other apparatus that had then just been designed to meet the requirements of the new method of both public and domestic illumination. It was the great day of what were then termed electric lighting systems, and of such systems the Exhibition contained a most brilliant display.

From the holding of that Exhibition, electric lighting, as we now know it, may be said practically to date, and to many, including myself, who visited it, it proved an inspiration. Sir William Preece became the apostle, or perhaps rather the major prophet, of the new electrical evangel, while Sir William Crookes, as he afterwards expressed it, came back from Paris "red-hot" and proceeded to light his house in London, not only laying with his own hands the necessary wires under the floor-boards in glass tubes, with plaster of Paris joints—wires that were still in use up to the date of his death—but even making his own lamps, with the result that by September, 1881, the house was lighted up by current supplied by a small Bürgen dynamo in the basement, driven by an Otto gas engine, and was, according to Crookes's own statement, the first house in London to be permanently lighted by electricity, though Colonel Crompton now claims that distinction for his house.

The first time I myself saw private house electric lighting was in 1882, when I was taken to see Lord Kelvin—then Sir William Thomson—who had just fitted up a gas engine and dynamo, together with a Faure accumulator with horizontal plates, in his laboratory, and was lighting both the laboratory and his adjacent house with Swan incandescent lamps.

I suppose I must have given some indication that I thought that electric lighting might be a good business to take up, for I remember Lord Kelvin advising me strongly against such a course, as it would be "nothing better than a plumber's job." I understand that I was not the only individual to whom Lord Kelvin, about that time, gave similar advice.

Another private electric light installation that I visited in 1882 was Cragside, where since 1879 Sir William, afterwards the first Lord Armstrong, had utilized the energy of a waterfall to produce electricity which was transmitted to the house by overhead wires over a distance of 1 500 yards. This was the first hydro-electric installation in this country, and also, I fancy, the first transmission in this country of considerable quantities of electrical energy over a fairly long distance.

It is perhaps not generally known that fuses, as originally introduced by Swan, were designed not as a safeguard to protect the wires against overloading or short-circuits, but in order to protect the lamps from over-running. When I went to the Armstrong works at Elswick in 1882, part of the drawing office had been electrically lighted by the Swan Company, and each incandescent lamp was fitted with a separate tinfoil fuse for this purpose. The precaution was, perhaps, a necessary one, as the lamps then cost 25s. each and were very fragile, while the arrangements for keeping a constant voltage were very crude.

Early in 1885 I was shown by Sir Charles Parsons his first steam turbine running at Gateshead, this being the identical machine that is on exhibition in the tea-room. This machine gave about 6 electrical horse-power when running at the great speed of 18 000 r.p.m. It is fitted with a very ingenious electro-pneumatic governor for maintaining a constant voltage, and provision is made for cooling the armature by oil circulation through its core. It is interesting to compare the parts of this machine as, for instance, its blading, with the very large steam turbines, on exactly the same principle, that have been constructed in recent years.

The Parsons steam turbine was first chiefly employed for the electric lighting of ships, and the first warship to be so fitted was the "Blanco Encalada," a Chilian battleship that had been sent to Elswick to have new boilers and armament. During a trial trip on board this vessel we had a somewhat curious and, I fancy, unique experience. During the early part of the trial the turbines were running perfectly and the lighting was excellent. After a time, however, the voltage fell and the lights grew dim. More steam was turned on and the voltage restored, only to fall again later on. Finally the light got so bad that the vessel had to return to the Tyne. The strange thing was that there was nothing apparent to account for the failure. There was plenty of steam and the turbine rotors were quite free when turned round. It was only when we removed the covers from the turbines that we found out what was wrong. It appeared that the engineers had put tallow into the new boilers to prevent priming, and on opening up the turbines we found that these were

* Since these reminiscences were communicated to the Institution, from inquiries made by the writer a number of Hughes's original microphones and other apparatus, mostly made with his own hands, and including the actual instrument he used in his 1879–80 experiments in wireless telegraphy, have been discovered, and are now on view in the Science Museum, South Kensington.

almost completely filled with tallow, the steam passages being all choked up with this substance.

The "Blanco Encalada" was also one of the first ships —the first really being the "Naniwa Kan," a Japanese cruiser completed at Elswick about 1885—to be fitted with wires and cables protected by lead sheathing instead of the costly teak casings previously employed. This system, which originated at Elswick, was promptly copied by the Admiralty and has since become very generally used on all classes of ships.

"Alas! the fleeting years glide away" and it is now a far cry to those distant days when the intrinsic interest of electric lighting was enhanced by the charm of novelty, and most of us were still young.

MR. J. C. VAUDREY.

Reminiscences in the Development of Electrical Engineering.

It is with some diffidence that I have accepted the invitation of the Institution to give my experiences of the early development of electricity supply. My work in Liverpool was started in 1882, in partnership with Mr. A. Bromley Holmes, and such success as I may claim there, was in collaboration with him. In 1879 I had visited Paris for the purpose of carefully studying the electrical exhibition that was held there in that year, and the impressions which the exhibition conveyed to me were, that a new field was being opened to engineers and others who were prepared to take some risks, and that the problems which would have to be solved would to a large extent be engineering ones.

I will now as shortly as possible indicate the work involved in the building up of the electric supply systems with which Mr. Holmes and I were concerned. The first Electric Lighting Act was passed in 1882, and, until that date, electric lighting had largely been confined to isolated installations in public buildings and experimental arc lighting for street illumination. Overhead cables suspended from poles or from house to house were at the time the only practical methods of distribution. A reliable meter was not then available.

At Liverpool the Company with which Mr. Holmes and I were associated, and which at first consisted of a few personal friends, commenced a system of lighting from a small supply station by means of overhead cables and, in default of a meter, a fixed price per lamp per annum was charged. The cost and risks attending overhead wires limited distribution on these lines. The local authorities at that date had not the right of control of the airway over the roads, but it was obvious that for the protection of the public any large system of overhead wires could not permanently be permitted, and in the year 1888 on our undertaking to lay an underground system of mains the city authorities consented to the granting to the Company of a licence from the Board of Trade for the public supply of electricity. It was the granting of this licence that at once changed the position of the Company, from what hitherto had been little more than an electric contracting undertaking, to that of a supplier of electricity with powers on similar lines to those conferred on gas and water companies. As underground distribution was the essence of the contract, I will commence with this. The experience gained of bitumen as an insulator for copper laid in underground conduits by the Callender Company in connection with two or three private lines seemed so satisfactory that this system was adopted in starting our underground system in Liverpool; this was in 1888.

As in all new enterprises there were many difficulties to be overcome: Were the cables to be laid under the pavements or under the roadways? Was cast iron or glazed pot to be used for the conduits? What methods were to be adopted for the protection of the conduits from accidental damage by picks, etc.? The question of joint boxes and making these water-tight, the details of services from the main to connect up customers through house walls, etc., etc. None of these matters could be permanently determined except by experience gained in practical working, and here I should like to acknowledge how much we were indebted to Mr. Callender (now Sir Thomas Callender) for his ever-ready help and collaboration in the development of this most important part of the supply system. Any public supply service must be accompanied by a satisfactory system of metering. There were several meters brought into the market in those early days, but it was not until Messrs. Chamberlain and Hookham and Messrs. Ferranti had developed and improved their original meters that much reliance could be placed on the accuracy of measurement.

The location of the early power house, owing to the small area over which the Company had control and the limited distance energy could economically be distributed at low pressure, was always a difficulty. Suitable sites where a canal or railway siding was available were seldom to be found.

It should not be forgotten that up to 1890 the pressure of the then available lamp did not exceed 110 volts, and even with the use of the three-wire system the economic range of distribution was very limited. In designing the power houses, uniformity of plan was as far as possible followed. Power units of 100 to 200 kW were as large as at that time were considered desirable. Duplicated batteries of accumulators were more or less essential to provide a continuous supply. It was found in practice fairly easy to man these houses with reliable men with very little previous electrical experience. At the time I remember some criticism being made as regards the apparent scattered nature of our stations and smallness of the power units, but after-experience justified the action then taken. The various stations gradually developed a demand in definite areas; and later, when the power was supplied from the new and larger power houses, these stations were admirably placed for substations and distributing

centres. The original plant, when it was found to be no longer wanted, generally realized fair prices. In the planning of a system of electricity supply it is necessary to cater for the resident in the suburbs as well as for the business portion of the community. In Liverpool one of the most important residential districts lay outside the boundary of the city, and was under the control of the Toxteth Local Board, and to satisfy what became in the end a pressing demand a Provisional Order was granted in 1889 to the Company for the lighting of this district. This necessitated a separate supply station within the area of the Order. Later on, the Corporation of Liverpool, under an Act of Parliament, incorporated this district within the city area; this enabled the Company to consolidate their interests by the Corporation assenting to the substitution for the original licence of a Provisional Order co-terminating with the Toxteth Order. At this period the Company possessed five relatively small power stations, which have formed the nucleus of the huge enterprise now under the control of the Corporation.

In 1889, as, I suppose, the result of our successful enterprise in Liverpool, Messrs. Chamberlain and Hookham, who had secured a Provisional Order for the electric lighting of the centre part of Birmingham, approached Mr. Holmes and me with a view to our taking over this Order and working it, as for personal reasons they had decided not to proceed with the work themselves. As a result we ultimately took the Order over by purchase, and it was decided between us that I should go to Birmingham and develop the work there, Mr. Holmes agreeing to help me in a consultative capacity and remaining in Liverpool. A Company was then formed with a local directorate, and I was appointed managing director and engineer. One of the Corporation conditions was that £50 000 capital should be issued before any work was proceeded with. The years 1889–90 were difficult for money raising, but with the energetic co-operation of the Board this condition was eventually complied with. I should like to mention that associated with me as one of the directors was the late Mr. Frank Albright, an old member of the Institution who with his local connection was a great help to me, coming as I did to a town where I was almost a stranger.

The history of the Birmingham undertaking forms my narrative from the time I left Liverpool in 1890, the experience gained there proving invaluable in the development of my new work. We commenced with the same initial difficulties of having a limited area in the centre of the city without canal or railway facilities, and with land in the hands of few owners and with many restrictions. Eventually a freehold site was secured and the work commenced with the laying down of three Willans-Crompton 220-kW plants with 3 Lancashire boilers. No condensing plant was possible and one had to be content with an exhaust-steam water-heater and later on, on further extensions, a Green's economizer. This station ultimately contained 6 Lancashire boilers and 4 Babcock water-tube boilers and 12 engine units, Willans and Bellis types; the stack was 210 ft. high by 10 ft. in diameter, in all rather a formidable plant to be fixed within a quarter of a mile of the centre of a city like Birmingham, as when in full work in the winter time there was an immense amount of coal delivered by cart, and ash removed, and it was by the best of good luck that we escaped injunctions for being a nuisance in more ways than one.

It is not easy for anyone to realize to-day the difficulties that had to be met in developing an entirely new enterprise like electricity supply in a large city. Thirty years ago the only public effort previously made in electric lighting in Birmingham was due to the work of Colonel Crompton in conjunction with the late Mr. Henry Lea, who obtained a Provisional Order for a small area of this city in 1882. The town hall and a few shops were lighted by means of a supply given from overhead wires, the current being generated in an adjacent factory. Owing to the non-fulfilment of the condition under which the Order was held, this Order was subsequently cancelled in 1886 and a good deal of money was lost; consequently it was not easy to re-inspire local confidence in the stability of a new electric lighting company as a business proposition for purposes of investment. These difficulties were eventually overcome and the scheme was launched. Site-hunting affords some interest, and in a limited area before one has finished one knows every possible and impossible piece of land on the market, and unless one is very careful there seems to be no limit as to what one may be asked to pay per yard. In the end we have to live up to our land—we are hampered for space, levels are not as we should wish them, and our neighbours, if we are not careful, will quickly find out that we are fair game for a claim for damages.

At the outset it is necessary to weigh carefully the cost of our works. For the first couple of years it is nearly certain that the revenue will hardly meet the expenses, at the same time if one is to obtain further capital, not only have one's expenses to be met but some profits must be made within a very short time. Our works and lay-out were therefore started with a view to a minimum of expenditure and arranged for easy ultimate extension.

At this time, as regards electric distribution, patents were claimed on the three-wire system with exaggerated royalties; these patents had been in existence for many years but had not been in practical use. Rather than submit to the claims about which there was some doubt as to their legality, only two wires were used out of the three laid; later, the patent having expired, no difficulty was experienced in making the necessary alterations and working the system as a three-wire one. Street boxes were at first apt to give trouble; occasionally water found a way in, and more than once slight explosions took place in the boxes, but it was soon found that such troubles could be prevented. In laying out the system, in addition to using Callender mains, it was thought that a considerable saving might be made by using copper strip stretched between insulators and laid through a concrete conduit under the pavement. This system had been carried out to some extent by Colonel Crompton in Kensington.

The main object was to economize in the immediate use of copper, additions to the mains being made by laying extra strips as required. In some of the streets the heavier feeding mains were laid in this way; in practice, however, it was found to be not altogether satisfactory. In the first place it was not easy to introduce new strip when the mains had to be increased, and later it was found very difficult to maintain any reasonable insulation, notwithstanding the use of glass insulators. Then the conduits formed an airway when any gas was about, and for some reason many of the conduits were very damp. After some years' experience it was decided to replace these mains by bitumen-insulated cables; fortunately, only a limited portion of the system had been laid in this way. The success of a public system of supply is linked up with the satisfaction of the consumer. In 1890 the electric wiring contractor in the provinces was practically non-existent, and the supply engineer had to provide for this deficiency. For the first few years I made it my business to see every customer on his premises to fix the position of the point of entry of the mains into the basement and the position of the meter, and it is to this policy I attribute a good deal of our freedom from many of the troubles and difficulties which frequently harass a new undertaking.

In looking back on the history of the two pioneering undertakings at Liverpool and Birmingham, it is a satisfaction to remember that both were commercially successful throughout the whole of their existence under company management, also that each was purchased by the Corporation on terms that afforded the shareholders a return commensurate with the risks and difficulties that had been met and surmounted, and lastly that the acquisition of the business by the Corporation has in each case proved a most excellent investment.

MR. ARTHUR WRIGHT.

Early Days of the Brighton Electricity Supply.

In these times of 200 000-kW power stations and of electricity supply networks covering more than 200 miles of country, it may be interesting to consider on what a small scale the electric supply business was started in this country, just 40 years ago, and on how small a business it was possible to make it a commercially paying proposition, when enterprise and capital were given a free hand, and the industry had not yet become entangled in this country by the restrictions with which our legislators had thought fit it should be controlled.

After an exhibition at Brighton of Brush arc lighting in December, 1881, Mr. Robert Hammond was persuaded to leave the plant in use there for a while longer, so that an experiment of running a circuit through the leading streets of the town could be tried, in order to give the shopkeepers a chance of testing the advertising power of the new light. This experimental circuit covered $1\frac{3}{4}$ miles, and supplied 16 arc lamps from a Robey engine and Brush arc machine, erected in Messrs. Reeds' foundry yard. It commenced the supply on 21st January, 1882. At the end of 7 days the experiment was discontinued for the purpose of making more suitable arrangements for the permanent supply to the very few enthusiastic consumers who were willing to pay 12s. per week per arc lamp. This permanent supply commenced on 27th February, 1882, and gradually the whole of 16 lamps was contracted for. In the spring of 1883 the business increased, and additional plant in the shape of a Brush 40-light dynamo and Marshall engine was installed. A rather crude analysis of the costs of supply was then made, indicating that the fixed annual charges amounted to £556 and the variable charges to £294, and that a 2-part tariff of 6s. per arc lamp per week, and 1s. 6d. for each carbon consumed would leave a gross profit of £180 per annum, to pay partly for the interest and depreciation of plant. This 2-part meterless tariff was first offered on 18th April, 1883, and was very successful in attracting new business, as it met the natural demand for charges based partly on the amount of electricity consumed.

In the summer of 1883, as the result of some experiments by Mr. Hammond at Chesterfield, sets of 10 Lane-Fox incandescent lamps with cut-out devices were installed on some premises in series with the arc lamps, and, as there were no suitable meters in those days, the charge was made of 12s. per set of 10 per week to be used daily up to 8.30 p.m. (lamp renewals extra).

In the spring of 1884 a method of metering the combined arc and incandescent lamps was devised, and improved safety lamp-protectors to each group were invented. The tariff for the incandescent lamps was changed in August, 1884, to one of $\frac{1}{2}$d. per lamp-hour if the average daily use during the quarter was more than 3 hours, and 1d. if it was less. The lamps used in these early days were made by Messrs. Lane-Fox, Bernstein, Woodhouse and Rawson, Swinburne and the Swan Co., and at a later period $3\frac{1}{2}$-ampere lamps were procurable, enabling a set of 3 instead of 10 lamps for private lighting purposes to be run in parallel.

Paraffin-cotton-covered twin and triple copper wires were used, stapled on to walls in the interior of buildings, and bare overhead wires slung on telegraph shackle insulators were employed without causing serious trouble, although the supply pressure at the dynamo terminals was 1 800 volts at peak load. Contract forms of these early years are exhibited.

By the end of 1884 the Hammond Company realized that a profitable and expanding business could now be developed. Consequently the Brighton Electric Light Company was formed, and a new power station and circuits were provided for. In 1885 some of the Brush machines and their individual circuits were used in series with one another at peak loads, thereby raising the working pressure considerably, resulting in increased economy and a distribution efficiency of 91 per cent.

A satisfactory form of constant-current dynamo regulator which, by using the principle of intermittently

A Chronological Survey of the Electricity Supply at Brighton up to the Year 1889.

Date	System of supply	Generating plant	Distribution of overhead lines	Load in lamps	No. of customers	Capital at end of year	Dividend paid	Tariff	Annual net profit after allowing for depreciation	Units sold	Notes
			miles			£	%		£		
21 Jan. 1882	Brush arc	16-light Brush dynamo and 12-h.p. Robey engine	1½	16	14	—	—	Free	—	—	Week's experimental supply to town
27 Feb. 1882	do.	do.	do.	do.	6	—	—	12s. per arc per week	—	—	Permanent supply from dusk until 11 p.m.
1883	do.	*Dynamos* 2 16-light and 1 40-light Brush machines *Engines* 1 12-h.p. Robey, 1 10-h.p. Hornsby, and 1 20-h.p. Marshall	3	—	—	—	—	6s. per arc per week and 1s. 6d. per carbon in lieu of metering	—	—	do.
1884	High-tension constant-current arcs and multiple series of incandescents	—	7	—	10	—	—	½d. per lamp-hour if more than 3 hours daily use; otherwise 1d. per lamp-hour	—	—	Lamp-protectors and electrolytic high-tension meters used
1885	do.	*Dynamos* 2 Brush 16-light and 3 Brush 40-light *Engines* 1 50-h.p. Fowler, 1 20-h.p. Marshall, 1 12-h.p. Robey, and 1 10-h.p. Hornsby	—	34 arc, 516 incandescent	—	—	—	1s. per unit if more than 10 per lamp per quarter; otherwise 1s. 4d.	—	—	Automatic vibrating shunt regulator used to maintain constant current
1886	do.	2 Brush 16-light and 5 Brush 40-light dynamos	11½	27 arc, 875 incandescent	40	7 240	4	do.	317 (or 3·68d. per unit)	20 625	—
1887	do.	*Dynamos* 2 Brush 16-arc and 5 Brush 40-arc *Engines* 2 Fowler and 1 Hornsby	15	2 970 10-c.p.	58	9 340	5	do.	773 for 15 months (or 4·48d. per unit)	41 309	Started day-and-night supply and changing over to a.c. system
1888	High-tension constant current and high-tension alternating current	2 Elwell-Parker alternators	20	5 500 10-c.p.	86	12 440	5	do.	532 (or 1·7d. per unit)	75 000	do.
1889	High-tension alternating current	1 Mordey and 2 Elwell-Parker alternators		—	—	—	—	—	—	—	All on a.c. system

shunting the dynamos field coils, enabled the current to be kept within 1 per cent of the standard value of 10 amperes was devised in December 1884. The circuits at this time extended into Hove, and amounted to a total length of 7 miles, and the customers included many of the larger hotels, private houses, theatres and churches. The lampholders, protectors, meters and regulators had to be made locally, and, in connection with these, mention should be made of the great inventive and constructive skill of Mr. G. F. Philpot, to whom, in conjunction with Messrs. Constable and Alderton, a great deal of the technical success of the system was due.

The result of the first year's trading of the Brighton Company was the earning of a 4 per cent dividend on a capital of £7 240, and the supply to 40 customers taking 27 arc lamps and 874 incandescent lamps.

Early in 1885 the load-factor tariff was changed from the lamp-hour on the meter basis to one at the rate of 1s. per kWh, if the quarter's consumption per standard lamp exceeded 10, and 1s. 4d. per kWh if it was less. The result of the Company's working at the end of 1887 was the payment of a 5 per cent dividend on a capital of £9 340, the increase in the number of customers supplied to 58, and the increase in the number of lamps to 34 arc lamps and 1 372 incandescent lamps, the circuits extending to 15 miles.

By the end of 1888 the Company's capital had grown to £12 440, on which a dividend of 5 per cent was paid, the number of customers had increased to 88, and that of the lamps to 5 500, the mileage of circuits to 20, and 75 000 kWh were sold.

Unfortunately, at the end of this year the Board of Trade (prematurely, in my opinion) advised the Company to apply for a Provisional Order under the Electric Lighting Acts, with the result that the opposition of the Brighton Municipality was roused, and their competition in electricity supply was seriously threatened. In view of this latter, Mr. Hammond very wisely vetoed my proposal for building a larger power station at Southwick on the water front, to meet the ever-increasing and profitable load.

In the same year the constant-current system was replaced by the more elastic alternating-current system with Lowrie Hall transformers, which had been used with success at Eastbourne, and Elwell Parker and Mordey alternators driven by two large Fowler engines. Suitable motor meters had to be invented and made locally to comply with the change of system, which latter proved to be immensely beneficial to the Company, and comparatively easy to operate, notwithstanding the slightly diminished distributing efficiency of the house-transformer system compared with the constant-current system.

Early in 1889 I severed my connection with the Brighton Company, and joined Dr. Ferranti's staff in London where I assisted in developing the alternating-current motor meters and transformers used in the large Deptford supply system.

Most of the technical developments in connection with the early electricity supply at Brighton were fully described by the late Mr. W. H. Snell in the *Electrician* (1888, vol. 20, p. 100).

The lesson I learnt from these early years was that electricity supply could be made profitable even on a small scale, given freedom for enterprise, suitable tariffs, and proper security for tenure. The accompanying table gives the above history in a convenient form.

FARADAY MEDAL.

At the Ordinary Meeting held on the 18th May, 1922, the President announced that the Council had established a Faraday Medal and that the first award of the medal had been made to Mr. Oliver Heaviside, F.R.S., Honorary Member. The President referred to the matter in the following terms :—

The President (Mr. J. S. Highfield) : I now have an announcement to make. At the meeting of the Council on the 5th January last, it was decided to institute a Bronze Medal to be designated "The Faraday Medal of the Institution of Electrical Engineers." The object of the medal is to commemorate the Fiftieth Anniversary of the first Ordinary Meeting of the Society of Telegraph Engineers, now the Institution of Electrical Engineers. The medal may be awarded by the Council not more frequently than once a year, either for notable scientific or industrial achievement in electrical engineering, or for conspicuous services rendered to the advancement of electrical science, without restriction as regards nationality, country of residence or membership of the Institution. With the medal will also be presented a parchment certificate of award. A bronze medal was chosen rather than a gold medal ; because a gold medal is a rather difficult piece of property to take care of, and a bronze medal, if properly executed, can be an equally beautiful work of art. It was desired that there should be no suggestion of any intrinsic value in the medal itself, but rather that it should owe its value, first, to the fact that it was to commemorate an important event in the history of this Institution, secondly, that it was offered for world-wide services without any restrictions, and, lastly, that it was hoped, as time proceeded, its importance would be advanced by the illustrious names of its holders. The design prepared by Mr. Metcalfe has been adopted. It was intended to announce the institution of the Faraday

Medal during the Commemoration Meetings, but circumstances arose which prevented this being done, and I feel considerable personal pleasure in the delay. Having been prevented from attending any of the meetings, it is pleasing to me to have the privilege of making this announcement and of thus taking part in the final Commemoration incident. I am still more pleased to be able to announce that the Council have made the first award to Oliver Heaviside. It will be remembered that during the Commemoration Meetings a message was sent to Mr. Heaviside from all present to the following effect :—

"The members of the Institution of Electrical Engineers assembled at the Commemoration Meetings now being held to celebrate the 50th anniversary of the first Meeting of the Society of Telegraph Engineers (now The Institution of Electrical Engineers) with their thoughts directed to all those who in earlier days laid the foundation of the science and industry which the Institution represents, desire to send a message of greeting and remembrance to Mr. Oliver Heaviside, F.R.S., Honorary Member of the Institution.

"In the course of the Meetings they have been again reminded of and have recognized the great importance of the classic work achieved by Mr. O. Heaviside and published by him in his papers and writings from 1887 onwards, and especially of his discovery of the importance of inductance in circuits for the transmission of telegraphic and telephonic signals without distortion, and of him as the originator of the methods now being universally applied for this purpose; and in no less measure of his investigations and discoveries relative to the propagation of electromagnetic waves in space, the results of which are now being utilized in wireless or space telegraphy and telephony.

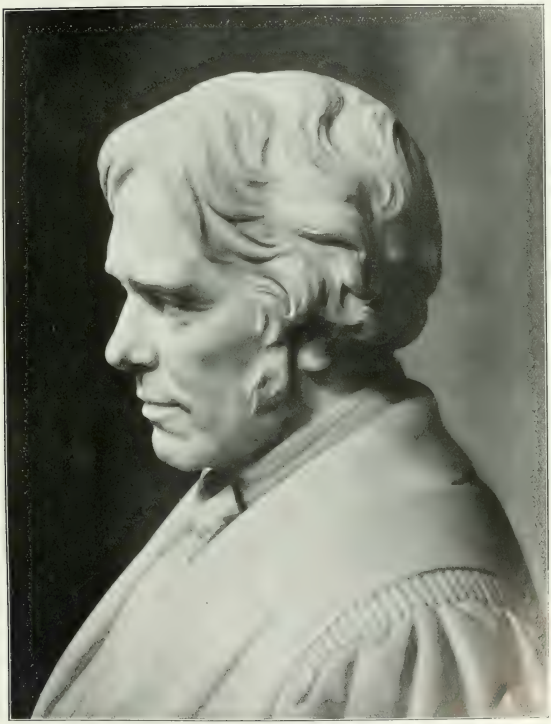
"They are convinced that, as now, so in the future, the name of Heaviside will rank among those of the great founders of the science of Applied Electricity."

I need say no more about the life-work of Oliver Heaviside. He is one of our famous men, who in his work displayed the wide and fearless view of the real pioneer. I am sure all present hope that in the evening of his life he may feel that those who follow him revere his name. I think it is especially fitting that the presentation of the medal should be made at this meeting when Sir Ernest Rutherford will deliver the Kelvin Lecture. Having done honour to one famous man, we shall now have the pleasure of hearing another. I am also very pleased that Sir Oliver Lodge is here to-night and that he will say a few words in support of my announcement. Right well have our famous men served us.

> Bless and praise we famous men,
> Men of little showing,
> For their work continueth
> And their work continueth—
> Broad and deep continueth,
> Great beyond their knowing.

Sir Oliver Lodge : I must say that this is an unexpected privilege, but it is always a pleasure to me to come, as I too seldom do, to meetings of this Institution, for here I find among electrical engineers a remarkably friendly atmosphere; astronomers and electrical engineers seem to have as few differences among each other as can be found among scientific men, or even among politicians. I congratulate this Institution on the use which it has made of its first Faraday Medal. A man like Oliver Heaviside, who wrote very abstrusely a good many years ago and who has retired into private life in the depths of the country, might easily have been forgotten and overlooked. You have sent him an eloquent message, which has just been read out, and you have made him the recipient of the first Faraday Medal. Although he may not care very much about medals, he cannot but appreciate the feeling which lies behind this medal, and the words of the message which were sent to him must give him joy. Furthermore, I understand that our President will go to see him and will present the medal which we cannot expect him to come here to receive.

It is unnecessary for me to recall what Heaviside did in the introduction of self-induction into the theory of cables, thus completing the Kelvin theory of cables which, in a manner, made Atlantic telegraphy possible in the 'sixties of last century. I suppose that I have been called upon to-night because I have lived throughout the whole of cable telegraphy—cable telegraphy may be said to have commenced in the same year that I was born, namely 1851—and perhaps because I am the other Oliver! Even in connection with the most recent work in which so many of our members are enthusiastically engaged—and no wonder, because the present state of wireless, now that the valves have come to some sort of perfection, is fascinating to everybody—we must remember that the long-distance transmission of waves round the earth would have been impossible but for the Heaviside layer—that upper layer of conducting material in the earth's atmosphere which, to the surprise of us older men, enables the waves to go right round to the Antipodes. Mr. Marconi made several discoveries in connection with wireless, such as the effect of sunlight; and he also found that it was possible for wireless signals to reach America round the curvature of the earth. He did not know the reason, but Eccles has explained it. Heaviside showed that an upper conducting layer would give that result; and that is, I believe, now the orthodox explanation, namely the presence of that layer, combined with the conductivity of the earth. Heaviside was also among the first to predict the increase of inertia shown by an electric charge when its speed of motion becomes great, and to work out the reaction between charges, waves, and motion, in a striking and diagrammatic manner. In conclusion I will say that I heartily welcome this gift and honour which has been done to a man who at first had to run the gauntlet of a good deal of criticism and whose discoveries were not received with that immediate acclamation which falls to the lot of a man like our lecturer to-night.



MICHAEL FARADAY (1791–1867).

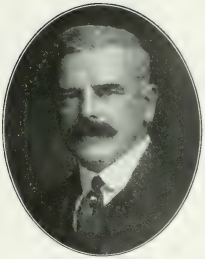
[From the statue by Boehm at the Royal Institution, London.]

The Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London.

Maull, photo.

Sir William Siemens (1823–1883).

(The first President of the Institution.)



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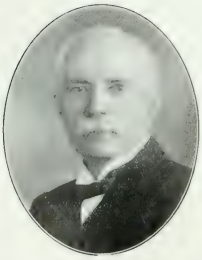

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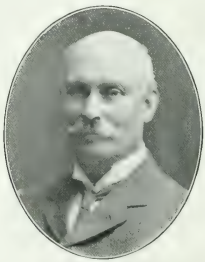

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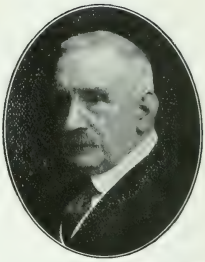

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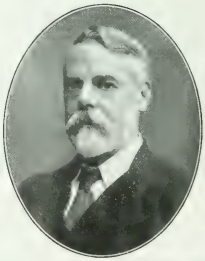

Baker, photo.

Mr. J. C. Vaudrey.

Wakefield photo.

Mr. H. W. Ravenshaw.

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Dr. A. E. Kennelly.

The Cave Studio, phots.
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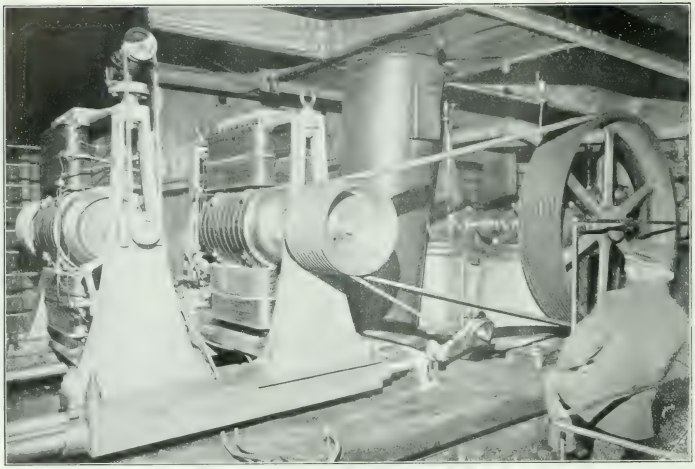
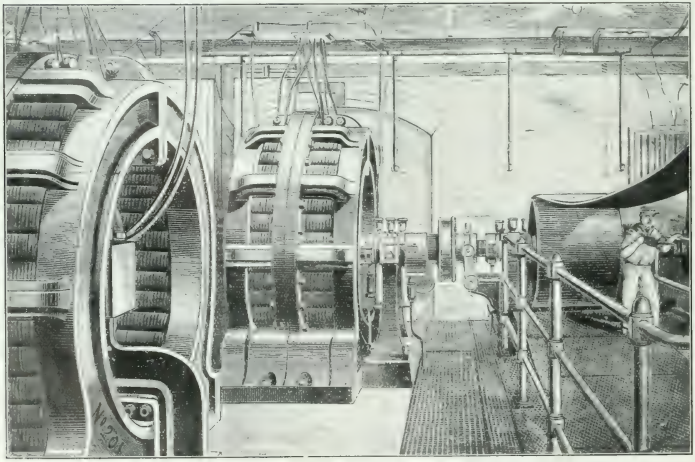
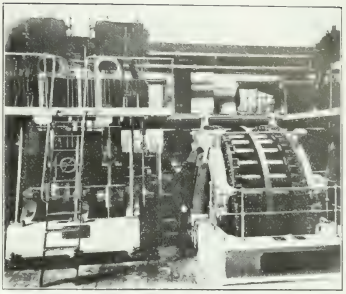


Electric Lighting Plant on the s.s. "Arizona," 1882.

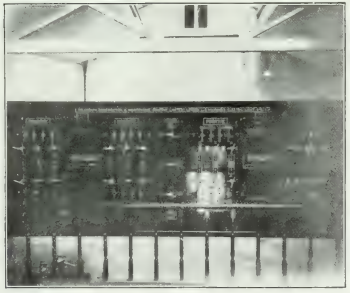


The Original 750 h.p. Grosvenor Gallery Dynamos.

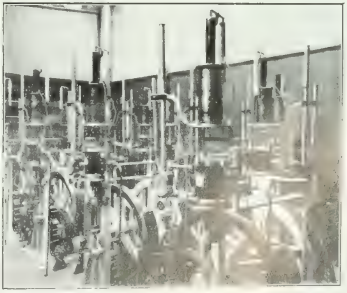
General view of engine-room.



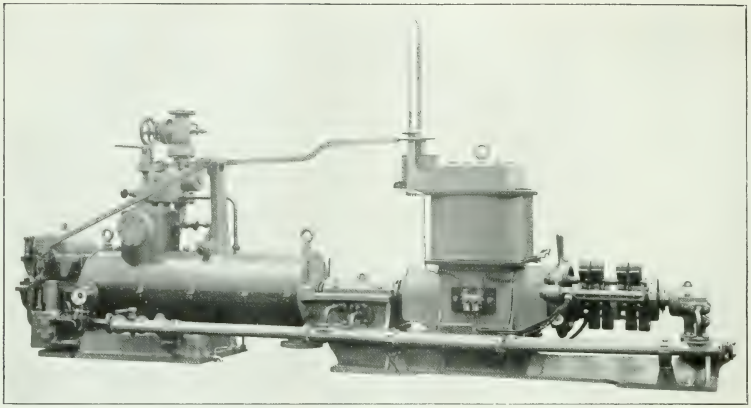
General view of one engine and dynamo.



Main switchboard.



General view of Gordon divided main apparatus.



Early 75 kW Single-ended Parallel-flow Turbo-dynamo, Showing the Oval Type Magnets and Heavy Brass-wire Brushes adopted in the First Turbine-driven Generators.

Cambridge Electric Supply Co.'s Power Station, Containing amongst other Machines the 120-kW Radial-flow Turbo-generator Tested by Sir Alfred Ewing in 1892.

ROTARY CONVERTERS, WITH SPECIAL REFERENCE TO RAILWAY ELECTRIFICATION.

By F. P. WHITAKER, Member.

(*Paper received 12th October, 1921; read at* THE INSTITUTION *16th February, before the* NORTH EASTERN CENTRE *13th February, before the* SOUTH MIDLAND CENTRE *22nd February, and before the* SCOTTISH CENTRE *11th April,* 1922.)

SUMMARY.

Railway electrification in this country will require converting machinery capable of operating from high-tension alternating-current systems with frequencies of 25 to 50 periods per second and delivering direct current at 1 500 volts.

For this class of service the rotary converter possesses many desirable characteristics, viz. ease and quickness of starting, high efficiency, high overload capacity, high power factor (especially on full load and overloads), freedom from limitation of high-tension a.c. voltage, reasonable flexibility of control of the d.c. voltage, reasonable freedom from harmonics in the alternating-current supply, and from undulations and ripples in the d.c. voltage delivered.

The limiting conditions in design and operation of such equipments are discussed, more particularly the effect of frequency on the generation of direct current at 1 500 volts, the effects of short-circuits and flash-overs, and the deviation of the d.c. voltage from a uniform value.

INTRODUCTION.

The consideration that is being given to the electrification of main-line as well as suburban railways would seem to make the present an opportune time for reviewing the problems of conversion that will be involved in these new developments.

The successful electrification of railways depends to a large extent on the supply of power at low cost, thus making it essential for the power to be generated in stations having a high load factor. It follows that it will be advantageous in this country for the frequency of the supply to railways to conform to the standard frequency of 50 periods per second, except when the railway will pass through districts in which the frequency has been decided by the large developments that took place prior to the standardization of a frequency of 50, in which case it would be advantageous for the railway supply to conform to the frequency of the district.

Converting apparatus will therefore be required to operate from generating stations supplying power at frequencies of 25, 40 and 50 periods per second, and will probably deliver power to the trains at a d.c. pressure of 1 500 volts. Abroad, requirements may demand an operating pressure of 3 000 volts (d.c.).

Converting apparatus for railway substations, in addition to being economical in first cost, maintenance and floor space, should preferably possess the following characteristics:—

It should be highly efficient.

It should be capable of carrying large overloads, more especially if situated in outlying substations.

It must be reliable and not likely to be put out of commission by ordinary overloads and short-circuits incidental to railway working.

The d.c. voltage should be as free as possible from ripples and undulations, so as to avoid interference with telephone and other communication circuits.

The power factor should be high, preferably unity or leading at loads above $\frac{3}{4}$ load, so that the voltage at the substation and surrounding district will be maintained at as constant a value as possible.

The d.c. voltage should be maintained at a reasonably constant value up to heavy overloads.

It should be capable of being built for operation on systems of 25 to 50 periods per second, whether from local supplies of 6 000 to 10 000 volts or from extra-high-tension feeders at still higher voltages, with practically equal efficiency.

It should be suitable for the application of automatic control.

It should be simple to operate and capable of being started up and connected to the direct-current bars in a short time.

If regenerative braking is found to be advantageous in a particular district, the equipments must be suitable for inverted operation.

The rotary converter has become the recognized conversion unit on 600-volt railway systems operating from 25-, 33- and 40-period systems, and this paper was written with the object of showing how far the modern rotary converter specially developed for the more exacting requirements of 1 500-V direct current is capable of fulfilling these conditions of service even when operating from 50-period systems.

THE EFFECT OF FREQUENCY AND D.C. VOLTAGE ON GENERAL DESIGN.

There is a practical limit to the average voltage that can exist between adjacent commutator segments, so that the number of segments between the positive and negative brush arms will increase with the d.c. voltage to be generated. If we assume a minimum width of commutator bar and mica, the distance between brush-arm centres will increase with the voltage.

A commutator bar moves from one row of brushes to the next row of like polarity, i.e. two complete pole-pitches, in one period, so that for a given distance between brush centres the peripheral speed of the commutator will increase proportionately to the number of periods. Thus the distance between brush-arm centres and, therefore, the peripheral speed of the commutator,

will increase with the d.c. voltage and, further, the peripheral speed of the commutator will increase with the number of periods. It should be interesting to see exactly what the limits are in this direction.

We shall have to assume that there is a minimum limit to the width of commutator bar and mica. This is not always fixed by the bar itself, but perhaps by the winding connected to the bars. I would suggest that the minimum width of bar and mica be taken as 0·20 inch.

Let V = voltage to be generated between brush arms;
v = assumed maximum permissible value of the average voltage per segment;
n = minimum number of commutator segments between positive and negative brush arms (neglecting limits imposed by phases, slots, etc.);
f = frequency of supply, in periods per second;
S = peripheral speed of the commutator, in feet per minute; and
d = minimum distance between the centres of positive and negative brushes, in inches.

The following relations will be obvious:—

$$n = V/v$$
$$d = n \times 0{\cdot}20 = (V/v) \times 0{\cdot}20$$
$$S = (2d/12) \times f \times 60 = 2(Vf)/v$$
$$V = Sv/2f$$

It will be seen that the maximum voltage that can be generated with a single commutator for any particular frequency, and with an assumed minimum width of commutator segments and mica, depends on the permissible values of average voltage per commutator bar and the peripheral speed of the commutator.

It is always difficult to settle limits even approximately in an industry that is rapidly advancing. Limits which have been considered unreasonably high have a way of becoming only too conservative.

With regard to the maximum permissible value of the average voltage per segment, I would suggest approximately—

13 volts for the higher-frequency rotary converters, and
15 volts for the lower-frequency machines.

Now, with regard to limiting peripheral speeds, speeds of 4 000 and 5 000 ft. per minute were at one time viewed with suspicion, but are now considered to be quite normal. Speeds of 6 000 ft. per minute have been adopted and have consistently given equally satisfactory service.

Speeds of 8 000 ft. per minute have been used experimentally over prolonged periods with heavy loads with excellent results, and there is every reason to believe that if advantage can be secured by such increase of peripheral speed on the higher-frequency high-voltage machines, such speeds will become quite common in the future. If we assume 13 for the maximum permissible value of the average voltage per commutator segment, and 8 000 ft. per minute as a limiting value for the peripheral speed of the commutator,

then $$V = \frac{8\,000 \times 13}{2f} = \frac{50\,000}{f} \text{ approx.}$$

i.e. the maximum d.c. voltage that can be conveniently generated in a rotary converter with a single commutator is approximately—

3 500	volts for	15	periods per	sec.
2 000	,,	25	,,	,,
1 500	,,	33	,,	,,
1 300	,,	40	,,	,,
1 000	,,	50	,,	,,

So that, while on 25 periods the generation of 1 500-V direct current has been accomplished in single-armature converting units, and such practice can be extended up to approximately 33 periods, above this frequency it is necessary to connect two 750-V rotary converters in series, or one single-unit motor converter could be used for such duty, as in that case the frequency to be taken in the above formula is that of the armature of the motor converter and not that of the supply.

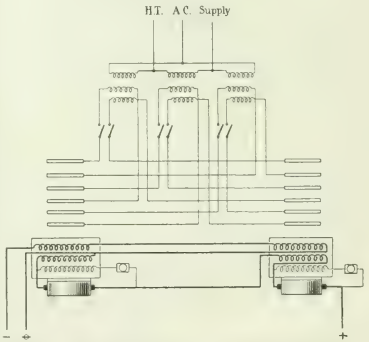


Fig. 1.—Two 750-volt rotary converters in series for 1 500-volt service.

In the case of series connection of rotary converters, the capacity of each machine will be half that of the complete unit, and the machine will be supplied from a separate winding on the secondary of the transformer (see Fig. 1).

Providing the complete unit is of about 1 200 kW capacity and above, there is little to be said against series working, but below this capacity the individual machines become too small for the satisfactory generation of 1 500-V direct current.

The series connection increases the floor space required per kilowatt, and this may be a limiting condition in some cases, but in other cases it may be advantageous on account of the reduced weights of each part.

The generation of 3 000-V direct current will generally be associated with a supply frequency of 50, and probably with relatively long alternating-current transmission. For such duty the synchronous motor-generator set is the most serviceable unit. The voltage of 3 000 could be generated on one commutator, providing the

frequency of the generator were kept down to about 15, but this would lead to a costly unit. It will be found more economical to generate such a pressure by connecting two 1 500-V generators in series, each generator operating at about 25 periods per second.

The Effect of 1 500-V Direct Current on the Detail Design of Converters.

The general proportions of both 25- and 50-period converters will not be seriously changed with the increased voltages;

A larger number of conductors of smaller section will have to be accommodated on the armature;

Increased space will be required for insulation;

Creepage distances will be increased; and

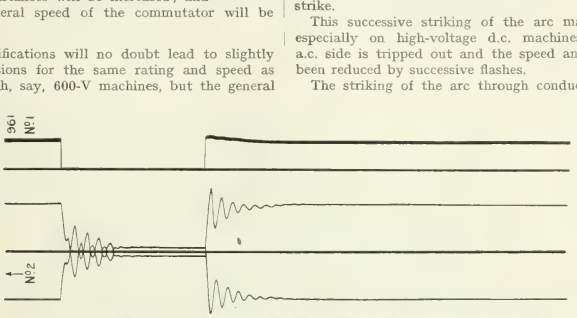
The peripheral speed of the commutator will be higher.

These modifications will no doubt lead to slightly larger dimensions for the same rating and speed as compared with, say, 600-V machines, but the general has momentarily to withstand currents beyond the commutating limit, and the armature reactions are seriously unbalanced. This results in an arc being drawn between the commutator segments and the brush-tips and adjacent metal parts.

While the short-circuit remains on the machine the terminal voltage is very low, but quantities of highly conducting vapours are produced. As soon as a circuit breaker disconnects the external short-circuit and allows the voltage around the commutator to increase, an arc strikes through this conducting vapour and forms a local short-circuit around the commutator. This short-circuit again reduces the voltage and the arc is quenched. The voltage again increases and, if sufficient conducting vapour be still present, the arc will again strike.

This successive striking of the arc may continue, especially on high-voltage d.c. machines, until the a.c. side is tripped out and the speed and field have been reduced by successive flashes.

The striking of the arc through conducting vapour



No. 1. Direct-current load suddenly switched off and then on (approx. 7 seconds between load off and on).
No. 2. Corresponding alternating current.

Fig. 2.

operating characteristics such as commutation, efficiency and power factor will remain unchanged.

A limiting condition, however, in railway working is that of short-circuit, and, no doubt, precautions will have to be taken in the design of apparatus for the higher d.c. voltages if perfectly satisfactory operation is to be maintained.

The liability to flash over is to some extent controlled by the detailed design of the machine, but even when the most conservative figures for design are used, high-voltage machines will flash over when subjected to short-circuits, if protected by the ordinary type of switchgear.

Owing to the energy of reversal in the short-circuited coils becoming too large, the saturation of the commutating flux path, and the high current density under the brushes, if the load on a converter is increased beyond a certain limit, serious sparking results. Also, if large loads be very suddenly applied, the normal balance between alternating-current and direct-current armature reaction is upset and this tends to produce sparking (see Fig. 2).

Under partial or complete short-circuits the machine produced under short-circuit is generally referred to as "flash-over" and results in damage to the commutator surface and brush-gear.

The explosive nature of the flash is also likely to force the copper vapour inside the armature and between the field spools, thus causing subsidiary earths and short-circuits which sooner or later result in breakdown.

Such operation is likely to prove a serious limit to the generation of high-voltage direct current with the ordinary type of apparatus.

It would seem necessary either to modify the normal design so as to make machines more self-protecting, or to provide additional apparatus for the purpose of protecting the machine. No doubt both methods can be utilized with advantage.

Manufacturers who have had experience with the design and operation of high-voltage d.c. machines have approached this matter in various ways, and I propose to outline the process of development followed by the firm with which I am connected.

Three 800-kW, 1 500-V rotary-converter equipments were originally supplied to the North-Eastern Railway for operation on the Shildon-Newport electrification,

from the local supply system at 40 periods. Each unit consisted of two 400-kW, 750-V rotary converters connected in series.

It was recognized that the short-circuit conditions, especially in the early days of the electrification, might be severe and, consequently, the machines were built

Fig. 5 illustrates one of these machines, the commutation on which was quite satisfactory up to 3 times full load.

When originally installed, the a.c. side of the machines was protected by a time-limit device with a view to clearing all short-circuits on the d.c. side. In practice

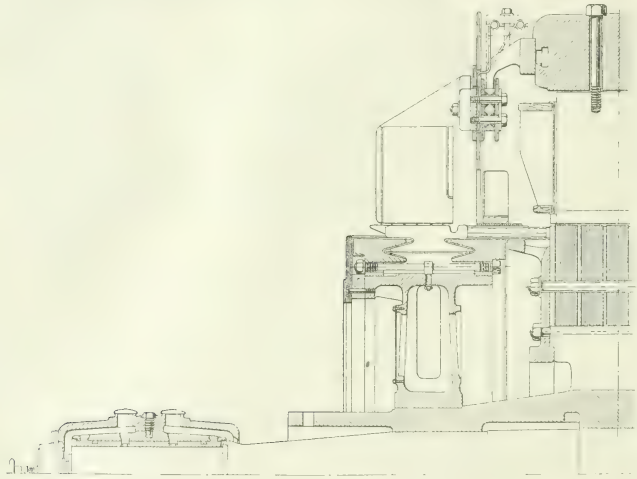


Fig. 3.

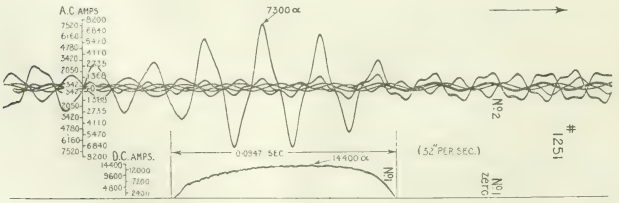


Fig. 4.

with a completely insulating and fireproof screen between the commutator and the rest of the machine, so that, in the event of flash-over, the arc would not penetrate into the more delicate parts of the machine.

Good clearance was provided between the positive and negative brush arms, and the operating details of the brush-gear were well protected.

it was found that these machines would take partial short-circuits up to about 5 times full load without flashing over, but above that point flashing over would result and, on severe short-circuits after the d.c. side had cleared, the machines would sometimes flash over again until the a.c. side cleared. Under such conditions the commutator was blackened and required attention.

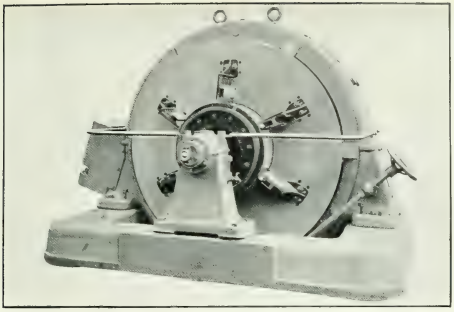


Fig. 5

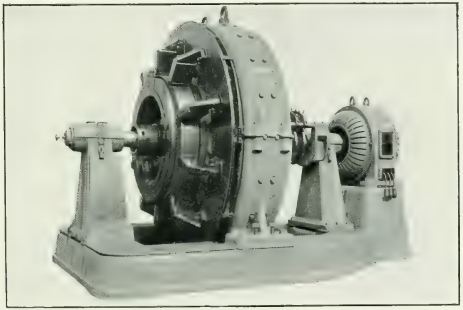


Fig. 6.

Fig. 7.

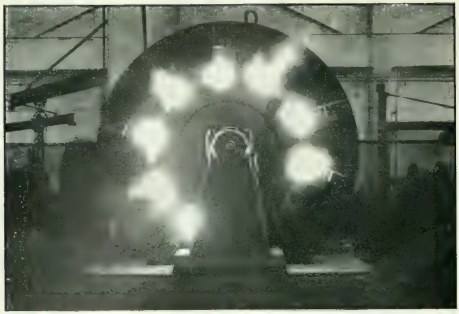


Fig. 8.

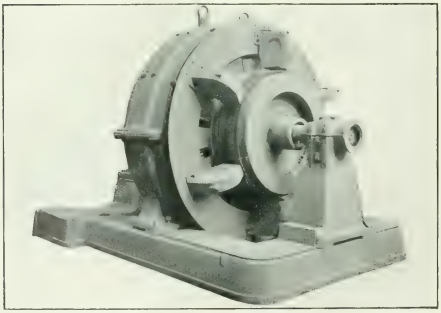


Fig. 9.

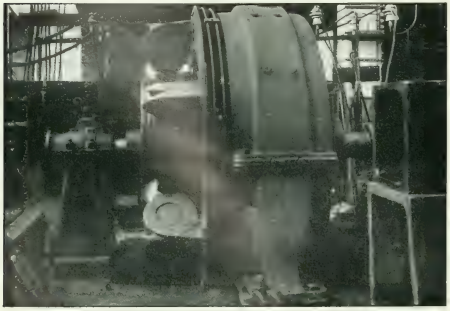


Fig. 10.

It was found advisable to reduce the severity of the flash by the use of instantaneous trips on the a.c. side of the machine.

Later, an opportunity was presented for installing a larger set, viz. a 1 200-kW unit (two 600-kW machines in series), and various novel features were introduced with a view to making the machines still more robust and self-protecting.

The diameter of the commutator was made practically the same as that of the armature, the armature bars being sweated directly into the commutator. With this construction it is impossible for the conducting vapour produced under short-circuit to penetrate inside the armature and cause subsidiary short-circuits.

The armature was provided with a propeller fan just at the back of the commutator, so arranged that it directed a strong blast of air axially over the commutator surface.

The d.c. brush-gear was completely enclosed inside cast metal brush-holders which are practically immune from damage due to flash-over.

Fig. 6 illustrates one of these machines, and Fig. 3 is a sectional view of the same machine.

The following advantages of this construction have been proved :—

- The conducting vapour produced under short-circuit is rapidly swept away by the blast of air, thus reducing the chance of flash-over when the d.c. voltage is restored on the opening of the d.c. circuit breaker.
- In the case of flash-over the resulting damage is almost negligible.
- The arc has not been known to re-strike.
- The conducting vapours are blown away from the important parts of the machine so that subsidiary short-circuits are not produced.
- The short-circuit is cleared so quickly that in most cases it is cleared by the d.c. circuit breaker, and the machine is left running on the a.c. side.

The following features were also incorporated in the design of these machines :—

- The distance between the centre line of the armature and the base-plate was made as large as possible, so as to give a large clearance between the brush arm and the base-plate and provide for air space all around the commutator.
- The distance between the commutator and the bearing pedestal was made large, and the pedestal and base-plate were shielded with insulation, to prevent the arc striking to earth.
- No part of the yoke for the brush brackets projects over the commutator, and this yoke is separated from the commutator and brush brackets by a thick layer of insulating material.
- The commutator segments are provided with arcing tips to prevent the deterioration which takes place at the ends of the commutator bars during flash-over.

When on test at the works this machine was coupled to a large turbo-alternator, and loaded up to full load on a water box. It was found possible to "dead short-circuit" this machine, clear the short-circuit on an ordinary circuit breaker, and leave the machine running on full load. Immediately after several short-circuits the machine would carry 3 times full load with good commutation.

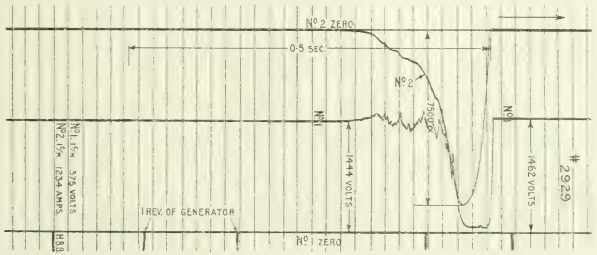


FIG. 11.

Fig. 4 is an oscillogram of one of these short-circuits, during which 19 times full-load current passed on the d.c. side.

Figs. 7 and 8 illustrate the machine under complete short-circuit and show the action of the air blast.

These machines have now been in operation for approximately 4 years; their performance has been excellent, and the cost of maintenance is very low.

We have recently experimented with a construction for magnetically driving the arc from the commutator surface. This scheme was applied to a 750-kW, 1 500-V compensated generator. When protected with an ordinary type of circuit breaker, it was found possible to short-circuit this generator completely when separately excited on the shunt winding, with or without the compound winding, without the slightest damage to the machine.

Fig. 9 illustrates the machine. Fig. 10 shows the machine under complete short-circuit, and Fig. 11 is an oscillogram of the short-circuit.

The commutator and brush-gear on this machine were in excellent condition after 40 complete short-circuits.

This construction has not yet been tried out in practice on a rotary converter, but it will no doubt be effective in reducing the damage to the surface of the commutator and brush-gear.

All the above developments have been in the direction of making the machine itself more robust and self-protecting.

The high-speed circuit breaker is a development in external apparatus to protect the machine. The successful operation depends on limiting the period of short-circuit and derangement of commutating conditions to such a small fraction of a second that very little conducting vapour is produced around the commutator, and there is little danger of the arc striking when the pressure is restored by the disconnection of the short-circuit.

It would appear sound practice to construct all high-voltage machines so that they are as self-protecting as possible, and, if the short-circuit conditions are severe, the machine should be further protected by a high-speed circuit breaker.

Successful operation on 1 500-V direct current has been accomplished with 40-period rotary converters protected by ordinary circuit breakers, and there is every reason to believe that ample margin exists for 50-period working, especially if the protective value of the high-speed circuit breaker is taken into account.

Effect of 1 500-V Direct Current and Frequency on General Performance.

Fig. 12 illustrates the performance that can be obtained from a 1 500-kW, 1 500-V unit operating on either 25 or 50 periods.

In the case of a 50-period supply the unit would consist of two 750-kW rotary converters in series.

The regulation, power factor and efficiency curves are based on a conservatively-rated unit capable of carrying :—

Full load continuously with less than 40 deg. C. rise.				
25	per cent overload	for	2	hours
50	,, ,,	,,	15	mins.
100	,, ,,	,,	3	mins.
200	,, ,,	,,	20	secs.

The 25-period equipment has an advantage in efficiency on the lower loads, but not such as to warrant the installation of 25-period equipment if a material gain in generation can be obtained by the use of 50 periods.

Power Factor.

Large peak loads will be carried in railway substations and, in order that the high-tension voltage at the substations and surrounding district will not be affected, the power factor of the converting apparatus should be as high as possible up to the maximum overload.

Apart from the economy of transmission at high power factors, the installation of apparatus taking lagging current at full load and overloads will increase the regulation difficulties on power systems, and may result in increased expenditure on equipment for maintaining the high-tension voltage.

Provided the reactance between the high-tension line and the slip-rings of the rotary converter is not made too large (this matter is further discussed under the heading of "Voltage Variation"), the power factor of rotary-converter equipments on the high-tension side can be maintained at unity power factor, even up to 3 times full load, without appreciable loss in efficiency.

Voltage Variation.

The ratio between the slip-ring and d.c. voltages on a rotary converter is practically fixed and can be

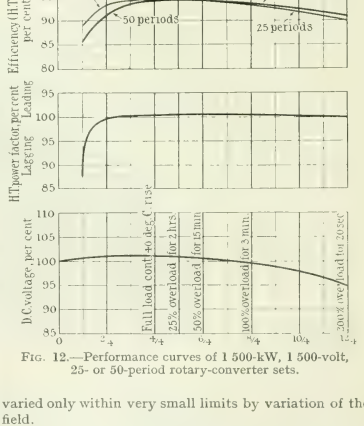


Fig. 12.—Performance curves of 1 500-kW, 1 500-volt, 25- or 50-period rotary-converter sets.

varied only within very small limits by variation of the field.

Reactance is usually inserted between the high-tension line and the slip-rings, so that the d.c. voltage can be controlled independently of the high-tension voltage.

The amount of reactance is usually defined by the voltage (expressed as a percentage of the a.c. voltage) that is produced by full-load current passing through the same.

Now, the voltage across the reactance is at right angles in phase to the current and, if the current is at right angles in phase to the supply pressure, the voltage produced across the reactance must be either added to or subtracted from the supply voltage.

Fig. 13 illustrates the case where 50 per cent of full-load lagging current is being drawn through a transformer with 20 per cent internal reactance. The low-

tension voltage of the transformer is 10 per cent lower than it would be if no lagging current were flowing. The same figure also illustrates the case where 50 per cent of full-load leading current is being drawn through a transformer with 20 per cent internal reactance. The low-tension voltage of the transformer is 10 per cent higher than it would be if no leading current were flowing.

The percentage change in voltage on no load at the slip-rings (and therefore in the d.c. voltage) is equal to

$$\text{Percentage reactance} \times \frac{\text{Change in wattless current}}{\text{Full-load current}}.$$

Considering only this aspect of the question, it would seem advantageous to obtain voltage variation by a small change of wattless current through a relatively high reactance; but when load conditions are studied the percentage reactance is more or less limited, especially in the case of a service where heavy and sudden peak loads are likely to be experienced.

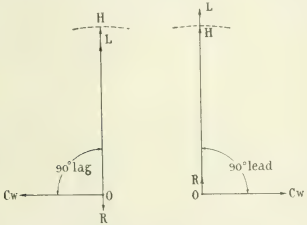


FIG. 13.—Vector diagrams when 50 per cent of full-load lagging current is drawn through a transformer with 20 per cent internal reactance.

OH represents H.T. voltage of transformer.
OL represents L.T. voltage of transformer.
OR represents reactance voltage of transformer.
Ocw represents wattless current, lagging or leading.

Energy current passing into the slip-rings of a rotary converter will be in phase with the slip-ring voltage, and therefore the voltage produced across the reactance will be at right angles in phase to the slip-ring voltage.

Fig. 14 illustrates the case where full-load energy current is passing into the slip-rings through 20 per cent reactance, and also indicates the conditions that would obtain on 3 times full load.

It will be seen that the effect of load current passing through the reactance is as follows:—

The drop in voltage produced at the slip-rings will be quite small on low values of reactance voltage, but large for high values. The final effect is to produce a voltage-regulation curve which departs from the straight line. The degree of curvature will depend on the reactance voltage which exists on maximum overload, and the curvature will be somewhat accentuated owing to the effect of this variation of voltage on the shunt field.

A phase difference will be created between the voltage at the slip-rings and that of the supply, so that the armature has to change its phase position with each change of load. If the change in load is very sudden, quite large synchronizing currents may flow, which will quickly bring the armature into the correct phase relationship with the voltage applied to the slip-rings, but will momentarily disturb the commutation. Fig. 2 illustrates this effect.

The power factor on the high-tension side of the transformer will either lag more or lead less than the power factor at the slip-rings, especially on overloads, when the reactance voltage is large and the phase displacement between the high-tension voltage and the slip-ring voltage is considerable.

So that, for ordinary services where the range of voltage is of more importance than the ability to withstand sudden and large overloads without disturbing the commutation of the machine or the voltage of the line, quite large values of reactance may be used to

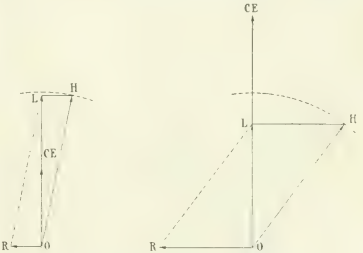


FIG. 14.—Vector diagrams when full-load energy passes into slip-rings through 20 per cent reactance.

OH represents H.T. voltage of transformer.
OL represents L.T. voltage of transformer.
OR represents reactance voltage of transformer.
OCE represents current in phase with rotary-converter voltage.

advantage. In railway working where little advantage is to be gained by the range of voltage or appreciable over-compounding, but where it is advantageous to keep the d.c. voltage as constant and the high-tension power factor as high as possible, and where it is necessary to reduce the momentary derangement of commutating conditions due to sudden loads, it is preferable to install machines compounded to give the same voltage at no load and 50 per cent overload, with a range of voltage from no load to 50 per cent overload by shunt control not exceeding + or − $2\frac{1}{2}$ per cent. Under such conditions the reactance can be kept relatively low.

Machines designed on these lines would have characteristics up to 3 times full load, as shown in Fig. 12.

Telephone Interference.

If interference with communication circuits is to be avoided, it is of importance that the d.c. voltage shall be as uniform and free as possible from ripples and undulations.

Oscillations in the d.c. pressure may be conveniently divided into the following groups:—

(1) Natural oscillations, i.e. those that exist in the d.c. voltage before the rotary converter is connected to the a.c. supply.
(2) Connection oscillations, i.e. those that result from connecting the rotary converter to the supply and assuming the supply to have a sine wave-shape.

oscillogram of the a.c. and d.c. voltages will give the natural a.c. and d.c. wave-shapes of the converter.*

The direct-current wave will generally be uniform, but may contain a high-frequency tooth ripple. Such ripples are due to the main field not remaining uniform, as regards time and space, for every position of the teeth with respect to the pole-faces.

The main flux may remain uniform in amount, but oscillate about a mean position; this is generally known as "flux-swinging." Again, it may remain stationary

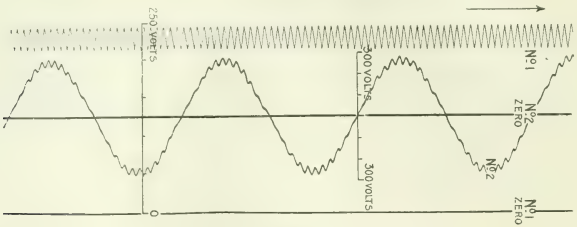


FIG. 15.

(3) Transference oscillations, i.e. those due to the deviation of the supply wave from the sine wave-form, and which are transferred from the a.c. to the d.c. system.
(4) Load oscillations, i.e. those produced by loading the converter. These may be divided into:—

(*a*) Saturation oscillations, due to the current passing into the rotary-converter armature being forced to take a shape other than a sine wave-shape.

in space, but may vary in strength about a mean value; this is generally known as pulsation.

Fig. 15 is an oscillogram of the natural wave-shape, in which the ripple was primarily produced by flux-swinging.

Fig. 16 is an oscillogram of the natural wave-shape, in which the ripple was primarily produced by flux pulsation.

The frequency of the tooth ripple corresponds to the periodicity with which the teeth pass any particular point in the field system, so that, assuming 30 slots

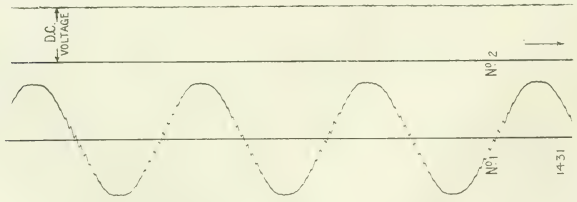


FIG. 16.

(*b*) Resistance oscillations, due to the superposition of the alternating and direct currents.
(*c*) Flux linkage and distribution oscillations, due to the resultant armature currents.

(1) *Natural oscillations.*—If a rotary converter (not connected to either a.c. or d.c. systems) be driven at normal speed and self-excited at normal voltage, an

per pair of poles as the minimum on 25 periods, and 48 slots per pair of poles on 50 periods, the frequency of the tooth ripple will vary between 750 and 2 400.

Now, the frequency to which the ordinary telephone

* The excitation for these natural wave-shapes corresponds to that required for unity power factor when the rotary converter is connected to the a.c. supply. It is not practicable to obtain the natural wave-shapes corresponding to operation at lagging or leading power factors.

receiver is most sensitive comes within this range, so that it is necessary to reduce the tooth ripple to the smallest possible figure.

Some of the earlier machines, particularly those which were constructed with heavy damping windings, gave very appreciable tooth ripples, but, with a finer appreciation of the ideals to be aimed at, these ripples have been reduced to very narrow limits.

With a view to determining possible limits for these oscillations, records have been kept on all machines manufactured over a period of years, and the maximum deviation of the d.c. voltage from the mean, due to tooth ripple, has not exceeded $\pm$ 1 per cent, and when the ripple has been known to be of importance it has been reduced to less than $\pm \frac{1}{2}$ per cent of the voltage. In fact, it has hardly been discernible in the oscillograph records.

These values apply to the natural d.c. wave-shape, and, because corresponding ripples will be found in the natural a.c. wave-shape, when the rotary converter is connected to the supply the tooth ripple will be somewhat reduced, due to the wave-shape equalization discussed in the next paragraph.

harmonics equal and opposite to those contained in the natural wave.

It is, therefore, necessary to see the effect on the d.c. wave of superimposing harmonics of various orders on the natural a.c. wave-shape of the rotary converter.

The third harmonic will not exist between rings 1 and 3, 3 and 5, 5 and 1, so that it need not be considered in the case of double delta-connected machines. However, in the case of diametrically-connected rotary converters a small third harmonic usually exists between rings 1 and 4. The application of a third harmonic of voltage to the terminals of a diametrically-connected six-phase rotary converter will introduce third-harmonic currents into the rotary-converter armature, and such currents will produce variations in the main flux distribution 6 times every period and so cause oscillations of this frequency to occur in the d.c. voltage.

A fifth harmonic of voltage applied to the terminals of a six-phase rotary will produce fifth-harmonic currents in the armature. These currents will produce a magnetic field which will rotate around the armature 5 times as fast as the fundamental field, in a direction opposite to that of the fundamental field. The fifth-harmonic

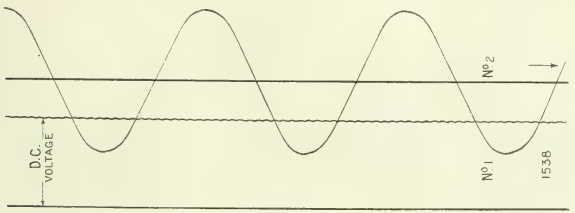


FIG. 17.

(2) *Connection oscillations.*—If the natural a.c. wave-shape of a rotary converter conforms to that of a sine wave, then no change in wave-shape would result if the rotary converter were connected to a supply with a pure sine wave-shape, and, because the same winding generates both a.c. and d.c. voltages, no change would result from the natural d.c. wave-shape.

The natural a.c. wave-shape, however, always differs slightly from the perfect sine wave-shape, and, if we assume no reactance between supply and slip-rings when such a machine is connected to a supply of perfect wave-shape, corrective currents between supply and machine force the wave-shapes of supply and rotary converter to coincide. If the supply be a large one the rotary-converter wave-shape will practically conform to the supply wave when connected to the supply. The corrective currents which flow into the armature to modify the natural a.c. wave-shape must also modify the natural d.c. wave-shape.

If the natural wave of a rotary converter contains harmonics and it is forced to assume a sine wave-shape by the corrective currents, it is equivalent to superimposing on the natural wave of the rotary converter, field will therefore move past the fundamental field 6 times per period.

Now, the fundamental field is stationary with respect to the main field system when the machine is running in synchronism, so that the fifth-harmonic field will sweep past any point in the main field system 6 times every period and so produce, in the d.c. voltage, oscillations of 6 times the frequency of the converter.

A seventh harmonic of voltage will produce a magnetic field which will rotate round the armature 7 times as fast as the fundamental field in the same direction as the fundamental field, so that the seventh-harmonic field will pass the fundamental 6 times per period, and will therefore produce oscillations of 6 times the frequency of the converter in the d.c. voltage.

Eleventh or thirteenth harmonics applied to the terminals of a six-phase machine will similarly produce oscillations of 12 times the frequency of the converter in the d.c. voltage. Other harmonics would produce oscillations on the d.c. side of frequencies a multiple of 6, but such oscillations, with the exception of tooth ripples, are generally negligible.

The phase of the oscillations on the d.c. side produced

by the various harmonics will depend on the position of the individual harmonic in the a.c. wave-shape.

The amplitude of any particular oscillation on the d.c. side will be equal to that of the harmonic producing the oscillation, and the resultant deviation on the d.c. side is the combination, in correct phase relationship, of all the oscillations produced by the various harmonics.

Generally, there is appreciable reactance between the rotary-converter slip-rings and the supply, and part of the discrepancy between the wave-shape of the rotary converter and that of the supply is absorbed by the corrective currents passing through the reactance. It is unnecessary, therefore, for the natural wave to change to such an extent; this is particularly so with regard to the higher harmonics. Reactance, therefore, is beneficial in reducing the amplitude of oscillations of frequencies of 6 and multiples thereof caused by connecting the rotary converter to the supply, but it tends to keep the tooth oscillation up to the full deviation found in the natural wave.

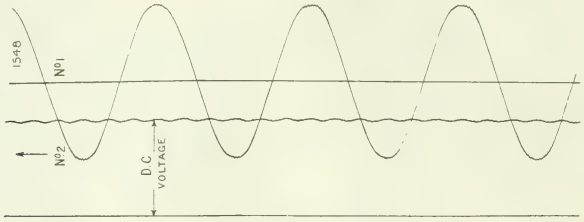


FIG. 18.

Oscillations due to connecting the rotary converter to the supply with sine wave-shape are usually quite small and of the order of ± 1 per cent.

Fig. 17 illustrates the natural wave-shapes of a 2 000-kW rotary converter.

Fig. 18 illustrates the oscillations due to connection to an alternator supplying practically a sine wave.

(3) *Transference oscillations.*—If the supply wave differs from a sine wave, the rotary-converter wave is further modified when it is connected to the supply. Again, it is equivalent to superimposing harmonics of voltage on the wave-shape of the rotary converter, and this leads to similar oscillations as described under the heading of "Connection oscillations."

The d.c. voltage wave can be materially changed by the deviation of the supply wave from the sine wave.

Fig. 19 illustrates the d.c. wave of a rotary converter when supplied from a generator wave with small deviation due to the lower harmonics and containing only a small tooth ripple.

Fig. 20 illustrates the d.c. wave of the same rotary converter when supplied by another generator wave with a somewhat larger deviation due to the lower harmonics, but again containing practically no tooth ripple.

Fig. 21 illustrates the d.c. wave of the same rotary converter when supplied by a generator possessing practically the same wave-shape as the rotary converter, except that there is a pronounced tooth ripple.

In general, rotary converters operate from systems containing a large variety of synchronous apparatus, and this results in the wave-shape of the supply being practically sinusoidal, but in cases where rotary converters will operate from a station containing one class of generator it is very important that the wave-shape of such generators should closely conform to that of a sine wave.

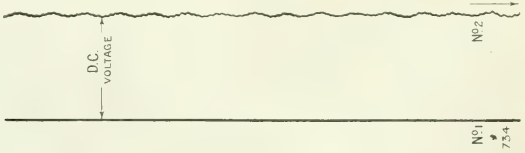


FIG. 19.

The present standard rule for the wave-shape of a.c. generators is entirely unsatisfactory, but is now under discussion, and it is in the final interests of all concerned that a new rule be formulated covering load as well as no-load conditions in which tolerances are reduced to the smallest figure consistent with reasonable protection of the manufacturer's interests.

Such a rule might mean the discarding in future of certain types of windings on generators built for general power-distribution purposes, but I believe such elimination would be beneficial to the industry, for windings which give good wave-shapes between phases tend to produce generators of economical design.

(4) *Load oscillations.*

(*a*) *Saturation oscillations.*—If we assume the natural wave of the rotary converter and the supply voltage to be sine-shaped, then the voltage across the reactance between the rotary converter and supply must also be sine-shaped. If the reactance voltage is strictly proportional to the current passing through it, then the current wave passing into the rotary converter will be sine-shaped. If, however, the reactance saturates with load, the current wave will be distorted, i.e. the current wave passing into the rotary-converter armature will have harmonics superimposed on the fundamental. These harmonics of current will produce magnetic fields similar to those described under the heading of "Connection oscillations" and will result in similar oscillations on the d.c. side of the converter. In this case, however, the magnitude of the harmonic currents is likely to be large, and the results on the d.c. side much more serious, more particularly if the transformer be star-connected. Reactance that saturates whether it be internal or external to the transformer should be avoided, in which case this type of oscillation disappears.

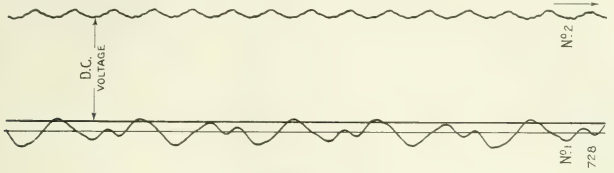


FIG. 20.

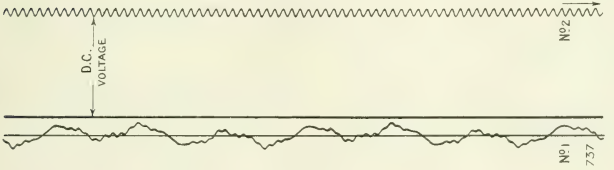


FIG. 21.

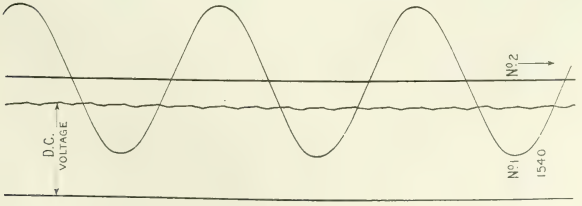


FIG. 22.

(*b*) *Resistance oscillations.*—These oscillations are due to the superposition of the alternating and direct currents. The former change their value and also their position with respect to the latter as the armature revolves. In a

six-phase machine the alternating-current values and positions are repeated 6 times per period. Small variations in the d.c. voltage are thus produced 6 times per period, but as the percentage copper loss in the armature of a rotary converter is very small, i.e. of the order of $\frac{1}{2}$ per cent, the oscillations due to this cause are very small indeed.

(*c*) *Flux linkage and distribution oscillations.*—Although the armature reaction due to the d.c. output neutralizes the armature reaction due to the a.c. input (neglecting losses) when taken over 180 electrical degrees, the currents at each point in the armature do not neutralize each other completely. The resultant currents produce local fluxes, change the flux distribution, and produce variations in the same. This results in slight oscillations in the d.c. voltage 6 times every period. These oscillations would appear to be quite small, and the total value due to resistance and flux oscillations is of the order of $\pm$ 1 per cent.

Fig. 22 illustrates the d.c. wave of the machine referred to in Fig. 18 when on full load. The wave includes any slight deviation of the generator wave from the sine wave-form when on full load.

General.—The oscillations on the d.c. side may be broadly classified as follows:—

(1) Tooth ripples.
(2) Undulations with a frequency of 6 per period. (The oscillations of 12 times normal frequency are usually very small.)

The tooth ripple on rotary converters for traction purposes need not exceed $\pm$ $\frac{1}{2}$ per cent of the d.c. voltage and, providing the supply conforms to a sine wave, the undulations of 6 times normal frequency need not exceed $\pm$ 2 per cent of the mean d.c. voltage on full load, the deviation being slightly greater on overloads. In cases of interference which have come under the author's notice the deviations have been considerably greater than the above, and it is not to be expected that any appreciable interference will occur on well-balanced telephone lines with ripples and undulations of this magnitude and frequency.

Wave-shape of Primary Current.

The departure of the primary current from approximately a sine wave-shape is usually associated with extra loss in transmission or generation and, in cases where the supply to converting apparatus is likely to be an appreciable percentage of the output of a generating station, it is important that the current wave-shape should approximate to a sine wave. Otherwise, increased losses and heating may result in the generating equipment. Further, if the primary network contains overhead transmission, interference with communication circuits may result from the distortion of the current wave.

The primary current-wave fed into rotary-converter equipments is usually distorted on no load on account of the small equalizing currents which flow between the supply and rotary converter, but these currents constitute a very small percentage of the full-load current.

The wave-shape of the primary current on load and overload on modern equipments will be found to approximate closely to a sine wave.

Automatic Substations.

The introduction of the automatic substation will considerably reduce the cost of attendance, but provision must be made for interest and depreciation on the extra control equipment required.

This extra cost will increase with the number of equipments per substation, but this is not so with the cost of attendance, so that the best field for automatic working is the single-unit substation.

In the past, however, on account of the cost of attendance, the tendency has been to group the converting apparatus, so that cases will arise in which automatic working will allow of a wider distribution of the converting plant, with resultant economy either in feeder copper or in copper losses, and consequent improvement in the distribution of voltage on the track.

Discussion at The Institution, 16 February, 1922.

Mr. R. T. Smith: I think it particularly opportune that we should discuss rotary converters for railway purposes when extensive schemes for railway electrification are being held up not so much for the want of money (although that is difficult enough to get) but for considerations of the financial position of railways due to the grouping under the Railway Act. On page 501 reference is made to the Report to the Ministry of Transport by the Advisory Committee on Railway Electrification, and the standard voltage is given as 1 500 at the trains. This 1 500 volts should be not at the trains, but at the busbars of the substation, while a pressure of either 750 or 3 000 volts d.c. is equally permitted, provided the Ministry of Transport is convinced that either is the proper voltage to use. The ruling feature affecting the design of all rotary converters, or all converting machinery for railway purposes, is that short-circuits do, and probably always will, occur on the track, and the converting apparatus which will best stand a short-circuit without stopping traffic is really more important to the railwayman than a small percentage gain in efficiency. A rotary converter may, I think, be defined as a bad motor which only needs to rotate at all in order to turn round the commutator. The direct-current part of the machine is never intended to be a generator, the conversion from alternating to direct current taking place in the windings and at the commutator. Yet on a short-circuit, after the voltage has fallen to zero as shown in Fig. 11, the machine tries to become a generator and does it very

badly. The author's method of blowing out the ring of copper vapour round the commutator, which is the feature of flash-over, is very ingenious, and on tests which I have seen at the B.T.H. works was most successful. The cheap first cost and the high efficiency of the rotary converter for 25-period supply are very attractive. The space (including transformers) occupied by two rotary converters in series, required for 1 500 volts d.c. with a supply at 50 periods is, however, likely to be large. One of the great difficulties in dealing with the measurement of efficiency, i.e. input divided by output (I refer to efficiency taken over a long period, say a year) is that very few railways or other concerns measure their input, although they may measure their output very carefully. It is extremely difficult to get reliable figures as to what the yearly efficiency of a converting station may be. In order, however, that railways may take advantage of the new capital stations contemplated under any scheme of dividing the country into supply districts (and it is only such capital stations which could really be useful to railways, on account of the large amounts of energy required), and in view of the fact that most of these capital stations will have frequencies of 50, the use of motor converters for producing direct current at 1 500 volts or of synchronous motor-generators or mercury-arc rectifiers must be considered. Over a period of 16 years I have used for electric traction on the Great Western Railway motor converters transforming direct from 6 500 volts a.c. to 600 volts d.c., and these have proved perfectly satisfactory. They have proved equally satisfactory elsewhere for 1 500 volts d.c. and can be used without transformers up to a.c. supply voltages of 12 000. The main advantage of the motor converter wherever a pressure of 1 500 volts has to be obtained seems to me to be that it is as good at 50 periods as at 25 periods, and also cheaper, and therefore the supply which is being standardized by the Electricity Commissioners can be used. There is no need to employ transformers to lower the a.c. pressure, unless this is above 12 000 volts. The machines are remarkably stable, and after short-circuits or shutting down they invariably excite in the right direction. Their annual efficiency (output divided by input) is as good, where comparisons can be made, as that obtainable with rotary converters, although the latter may have test-efficiencies 3 or 4 per cent higher than the motor converters. Motor converters need less floor space and switchgear than rotary converters, provided that no transformers are required with the former, and in this case are little if at all more expensive than rotary converters with transformers. In spite of this claim that the motor converter is a thoroughly useful and reliable machine for railway work, I think I can assure the author that people will continue to buy rotary converters until the mercury-arc rectifier becomes so reliable and so reduced in cost from its present prohibitive price as to take their place, or a better method of obtaining 1 500 volts is produced. In conclusion, I should like to say that in my opinion the information contained in the second part of the paper as to the effect of wave-form disturbances on communication circuits will be very useful indeed to railway and Post Office engineers.

Mr. J. R. Cowie : On page 502 the maximum voltage for a rotary converter is stated to be 1 000 volts d.c. at 50 periods. In the case of a 3 000-kW machine, therefore, it is necessary to have three machines in series in order to get 3 000 volts. With a synchronous machine, two machines in series are necessary and a transformer must be used. With a La Cour converter two machines in series must also be used, but the equivalent of approximately 25 periods in the d.c. armature is obtained, and therefore there is less liability to flash over; so that there is something to be said for the synchronous machine and a good deal for the La Cour converter. Mercury-arc rectifiers are, theoretically, very good, but they will have to be constructed much better mechanically than some of them are at present. The next point is the question of flash-over. In Fig. 4 the short-circuit current is approximately 14 000 amperes. Such a current can be reduced to approximately 6 000 amperes by the use of high-speed circuit-breaker switchgear. The maximum peak was reached in Fig. 4 in approximately 0·05 second; this time would be less if a high-speed circuit breaker were used. I am in entire agreement with what the author says about the necessity for guarding brush-gear. To the methods he gives, however, must be added high-speed circuit breakers, which do not require to be fitted throughout, but only to insert a limiting resistance to protect the machine. An important point not touched on in the paper is one which has caused a good deal of trouble in ordinary commercial work, i.e. the question of slip-rings. Personally, I have not yet found a satisfactory a.c. slip-ring brush; the dust from these brushes covers the whole of the windings and, when a short-circuit occurs, rises in a cloud. I should like the author to extend his experiments to include slip-rings, and I think that, having got so far as to make rotary converters for 1 000 volts, 50 periods, it will not be long before he gives us machines for 1 500 volts, 50 periods, and then we shall have the ideal machine for 3 000-volt railway work. I now propose to show one or two slides illustrating high-speed circuit breakers. The function of the apparatus shown in the first is simply to insert a resistance and reduce the amount of current which the rotary converter has to carry. The next slide shows the handle mechanism and the operating trip-gear. The third slide is of an actual installation at 3 000 volts d.c. The gear is absolutely enclosed. The last slide shows the main busbar, behind which is the high-speed switch with limiting resistance, and beyond that the group of feeders arranged so that the high-speed switch is inserted between the machine and the feeder group. The busbar is divided into sections of one or two machines, and high-speed circuit breakers are inserted between the sections. With such a system approximately 3 times full load on the commutator is obtained under short-circuit conditions.

Colonel H. E. O'Brien : We have had some experience with 1 350-volt rotary converters at 25 periods. These machines, which work on the Manchester–Bury line, were designed in about 1915, and a great deal of progress has since been made. At first considerable trouble was experienced with the machines, but the

compound winding was taken off, and since then the trouble has not been serious. This fortunate experience has probably been due to the batteries, which work in conjunction with the substations and prevent any serious interruption to traffic. Any apparatus designed to prevent flashing-over is very welcome. On the other hand, from the point of view of the maintenance of the machine the flash-overs are not very serious. I notice, from the photographs reproduced in the paper, that the flash-over does not seem to take place all round the commutator; it appears often to be confined to a particular pair of brushes. In any case, the damage done is not very great, and the brush-gear in the Lancashire and Yorkshire machines has been in operation since 1916, and is only now beginning to show signs of requiring heavy repairs. I think that one very important result of this advance in dealing with 1 500-volt rotary converters is the improvement which we shall be enabled to make in the load factor of the substations. This load factor is limited to a considerable extent by the amount of plant that, with the 1 500-volt rotary converters, will have to be run in order to avoid flashing-over. With these machines, flashing-over sometimes—in fact, fairly often—takes place without any definite short-circuit occurring. I think that the mercury-arc rectifier is a formidable rival to the machines described by the author. I admit that a good deal of auxiliary apparatus is required, but I think there can be no question that the mercury-arc rectifier functions very well on a very fluctuating load. It appears, however, to have one disadvantage which the rotary converter has not got, i.e. it cannot be put suddenly on load after a prolonged shut-down; it requires warming up, a process which may take from 20 to 25 minutes. If a rotary converter had to be warmed up for 20 minutes before it could be put on load, the amount of plant required in the substation under certain circumstances would be considerably increased. I am in agreement with Mr. Cowie in thinking that we shall soon have a rotary converter to work at 1 500 volts and 50 periods.

Mr. G. A. Juhlin: I think that the author has given a very thorough summary of the requirements for converting plant for railway work, but I am of the opinion that the question of reliability rather than that of efficiency should have taken the first place. There are one or two points in the paper with which I do not quite agree. The author gives a limit of 13 volts per bar for 50-period machines, and I think that this value is too low. There are many thousands of kilowatts of 50-period plant with between 15 and 16 volts between bars operating in every way satisfactorily in this country. I think that the author is very conservative in regard to the thickness of commutator bars. There are machines operating in London with bars 0·14 inch thick, so that this point should therefore materially help in the production of high-voltage rotary converters. I note that the author has given a limit of 8 000 ft. per min. for commutator speeds. I take it that he refers to the cylindrical type of commutator. I should like him to say if there are any machines except direct-current turbo-generators operating with such commutator speeds. While I do not believe that it is impossible to run at such a speed, one would certainly anticipate considerable trouble on high-voltage machines which require narrow brushes, as chattering is likely to occur. It is possible, however, by the use of a radial-type commutator, to increase considerably the peripheral speed. Machines are at present operating with radial commutators without the slightest difficulty up to speeds of 11 000 ft. per min. Assuming a limit of 15 volts per bar, an average commutator speed of 9 000 ft. per min. on a radial commutator, and a thickness of commutator bar of, say, 0·175 inch in applying the author's formula, it will be found that there should be no difficulty whatever in producing a 1 500-volt, 50-period rotary converter. Such a machine is now being built and will shortly be on test. The method employed by the author for preventing a flash-over is very interesting. It is difficult, however, from a study of the paper to form any judgment as to the

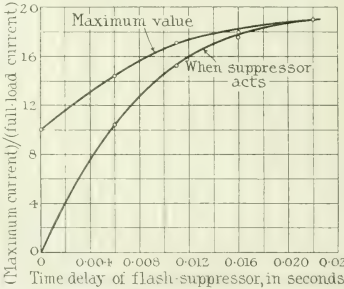


FIG. A.—Curves showing direct-current short-circuit characteristics of 1 000-kW, 1 500-volt generators, with and without flash-suppressor.

relative importance of the blow-out, as compared with the fan which apparently was provided for the machines described, and also the effect of the high-speed circuit breaker. In connection with the question of flash-over, I should like to refer to a method which has been developed in connection with high-voltage d.c. generators. The principle in this method is to reduce the voltage at the brushes of the d.c. generator. To effect this, slip-rings are provided which are short-circuited when a sudden overload or a short-circuit is thrown on to the d.c. system. The slip-rings are short-circuited by means of very high-speed switches. A large number of tests were made on some 2 000-kW units which consisted of two 1 000-kW, 1 500-volt d.c. generators built by the Westinghouse Company, Pittsburgh. These machines would carry a short-circuit of 7½ times normal load without any noticeable flashing on the brushes, and short-circuits up to 14 times normal full-load current were thrown on to the machines without causing flashing-over. The effect of the time limit on the short-circuiting switch

was investigated and it was found that this had an appreciably bearing on the flashing of the brushes, due to the fact that the maximum value to which the current rose depended on the speed with which the switch short-circuited the slip-rings. Fig. A shows the relation between the time and the maximum current value observed. This undoubtedly indicates that the high-speed breaker has a material bearing on the ability of the machine to withstand short-circuits without flashing-over. This point was indeed mentioned by the author in referring to some of the slides shown but it was not brought out clearly in the paper. The author's contribution to the question of ripples is of great interest and value. I should like to ask him, however, if he would explain how the third harmonic appears as a sixth harmonic on the d.c. side, as this is not clear from the paper.

Dr. S. P. Smith: The proposal put forward by the author to meet the problem of 1 500 volts at 50 periods does not seem to be acceptable, although it may have been a good compromise when such machines were built a few years ago for the Newport 40-period line. It is probably too late in the day to propose two machines in series for 1 500 volts and 50 periods, as single machines capable of running at that pressure and periodicity have already been built and are now in operation. I do not think that the author has faced the problem in the right manner. It is true he mentions the difficulties, but he does not appear to show how they can be overcome. Mr. Juhlin mentioned one solution, viz. higher commutator speeds. This was pointed out some years ago by Prof. Miles Walker. I am not sure if it is desirable to put shrink-rings on a commutator of a high-voltage rotary converter, but there is no doubt that higher peripheral speeds will be used. The limit given in the paper for the pressure between segments is too low. It is useless to try to keep this down to 13 volts for high-frequency rotary converters; quite satisfactory machines have been built with a pressure of 20 volts between segments. The chief factor in the majority of these machines is not so much the pitch of the commutator segments as the thickness of the mica. Some machines have been built with bars as narrow as about 3 mm, with about $1\frac{1}{4}$ mm of mica between. If such limits as these be taken, i.e. a commutator segment pitch of about 0·16 inch, a peripheral speed of about 8 000 ft. per min., and a voltage of 15 between bars, then 1 500 volts at 50 periods can be obtained. Possibly by the time that is generally done the rotary converter will suffer the same fate as the d.c. turbo-generator. In the case of that machine, when we had at last learnt how to build the machine satisfactorily up to about 1 000 kW at fairly high peripheral speeds, the rotary converter came into fashion and the turbo-generator was ousted from the market. Possibly by the time we learn how to build commercially these 1 500-volt, 50-period machines for large powers, the mercury-arc rectifier will oust it in a similar manner. I am, like Mr. Juhlin, in doubt as to how the author treats harmonics. On page 509 he says: "The application of a third harmonic of voltage to the terminals of a diametrically-connected six-phase rotary converter will introduce third-harmonic currents into the rotary-converter armature, and such currents will produce variations in the main flux distribution 6 times every period." That is difficult to understand. One can understand how these may be obtained with the fifth and seventh in the manner explained, but I have not discovered any means whereby the former effect can produce this result. If the third harmonic is a pulsating flux, which I think it is, it is probable that it will react on the field as in the reactions in a single-phase alternator, but I think any such reaction would never get into the field winding at all if the damping winding were effective. The cause of the blackening referred to is probably the fifth and seventh harmonics. With regard to short-circuits, the rapid cut-out has been mentioned, and this is very important. Colonel O'Brien referred to the trouble which he experienced before he cut out the compound winding, but it is probable that reversing the winding might have improved the result. The principal object is to reduce the pressure and prevent the short-circuit current from rising to an enormous value, and whether that is done by reversing the series winding or in some other way, e.g. by preventing the current rising in the shunt winding, is immaterial. It is very important indeed that the ampere-turns acting on the interpoles should be strong enough to prevent the flux reversing in the case of short-circuit. The question of wave-shape is also very important. On page 510 the author mentions that the present standard rule for the wave-shape of a.c. generators is entirely unsatisfactory, and states that it is now under discussion. The ideal to aim at, both with the a.c. generator and with the rotary converter—and I would add with the mercury-arc rectifier—is the elimination of all ripples.

Mr. P. R. Wray: There is no question of more importance than that of capital charges, and a vital point in this connection is that of the rating of the rotary converter. What overload capacity do we require? The author has given figures showing the excessive overloads that his designs will carry; they reflect great credit on his skill as a designer, but such overloads have to be paid for and I doubt very much if they are really needed unless the circumstances are exceptional, although they are frequently demanded. The total amount spent in overload ratings must in the aggregate be enormous, and in many cases such ratings are never used, earn no money on their investment, and are so much dead weight on the whole of the electrical supply industry. As the art of design has now reached such a high standard of excellence, and as designers are able to foretell with exactitude the capabilities of their machines, there does not seem to be any necessity to demand these sustained overload ratings unless they can be economically utilized. The sole justification for demanding them in the case of rotary converters is that they may be utilized on peak loads in the morning and evening or whenever they occur, but a little consideration will show that if the machines are run under such conditions the maintenance charges will eliminate any possible saving in the capital charges. It must not be forgotten that if a machine is run at, say, 125 per cent rating, the normal fluctua-

tions in the load may and do frequently exceed 200 per cent, and under such conditions the commutator wear is likely to be excessive as, although we demand perfect commutation at full load, we expect only a moderate performance in this respect on overloads. Where a large number of substations are feeding into a common system, as is usually the case on a railway, there appears to be no justification for sustained overload ratings. The machines should be run continually at the limit of their capacity, i.e. as far as is consistent with the load available. A short, moderate overload test to indicate the capabilities of the machine with the normal fluctuations of the load, and a momentary heavy overload test to indicate its capabilities for dealing with abnormal conditions, are all that is required. An overload of 50 per cent for a few minutes and of 150 per cent for a few seconds should be ample for all normal requirements, unless the weights and accelerations to be dealt with, or the circumstances, are somewhat unusual.

Mr. W. E. Highfield: The author not only has produced an exceedingly robust machine, but has restored the design of rotary converters to its classical lines. It is only two or three years since this question was fully ventilated in the American Press and the causes of short-circuits were very thoroughly investigated. The rotary converter design then produced was a definitely retrograde step; instead of cutting at the root of the difficulty, the distance between the brush-arms was filled up solidly with flash guards, flame shields, wire netting, etc. That not only obscured the issue of design but definitely defeated its object, because any sort of insulation carbonizes sooner or later and becomes a partial conductor. It was also bad from the point of view of the running staff, because the machine was masked and could not be rapidly cleaned or inspected. The author's machine has completely changed this type of design, and it is difficult to stress too highly the value of that achievement. The author gives the limitations of his design very conservatively. He practically leaves the 3 000-volt system to be dealt with by the motor-generator. I think, however, that at this point rotary converter design will readily borrow from motor-generator design. The Americans have made no such mistake with motor-generators as they have with rotary converters. The Chicago and Milwaukee machines withstood short-circuits equivalent to 20 times full-load and were perfectly open machines, in that their commutators were accessible. They were carefully compensated, so that the curve of E.M.F. around the commutator remained practically constant, irrespective of load. The rotary converter is an imperfectly compensated machine, and an interpole under certain conditions of load will give a definitely bad effect. I believe Mr. B. G. Lamme was the first to point out this and also that it occurs when, at the maximum overload, the direct current is interrupted. I think that careful compensation around the interpole space will benefit the design and prevent the E.M.F. wave from being drawn out unduly. I should like to call attention to the design of commutator given in the paper. There are two types of insulation, i.e. the mica in the carbon track and the air in the flame track. The author's device is very ingenious; the action of the magnetic blow-out and the fan must be very positive, even violent, so that the flame is transferred from the mica to the air. I know from experience that greater liberties can be taken with air insulation than with mica. I have built machines which ran with 89 volts per bar under very onerous conditions of load with air-insulated commutators and a fan blowing straight through, and no flash-overs occurred. The question of commutator speed seems to me to depend on the design of brush-holders. I have seen brush-holders that would run successfully at 10 000 ft. per min., and others that would not run at 3 000. The point is that if there is any irregularity in the commutator, then, at a surface speed of 8 000 ft. per min., a definite blow is given to the carbon, which leaves the surface and, before it returns, the commutator has moved some distance forward. This is almost certain to cause a flash. If the author were to add to the paper the speeds at which the camera shutter and also the circuit breaker opened, it would enhance the value of the photographs showing the flashes.

Major A. M. Taylor: The author tells us how to construct a rotary converter which shall take 750 volts across its commutator, thus enabling us to obtain 1 500 volts by putting two rotary converters in series and earthing the middle point. He apparently considers a voltage of 1 500 to be sufficient for railway electrification, by which I assume he means main-line electrification. On this point I wish to join issue with him. Let us consider a main-line section between London and Birmingham. On such a section there are at present some 15 passenger trains each way in a day of 12 hours. This gives a time headway of 0·8 hour per train, which, at an average speed of 45 m.p.h., would give an actual space headway of 36 miles between any two trains. The line being 110 miles long is thus divided up into approximately three sections, on each of which there are two trains at any moment moving in opposite directions. The natural and proper spacing for the substations on such a line would be 36 miles apart. At 1 500 volts, however, this would be quite impossible; in fact, to utilize to the best advantage the feeder copper from the substation the radius of "feed" on either side of the latter should not exceed 3 miles, which means that each substation would have to be restricted to feeding a length of line represented by 6 miles, and even then the average loss in the feeders would be of the order of 10 per cent. We arrive therefore, assuming that each locomotive takes 1 000 kW, at the following conclusions. The total energy required for the whole line is only 6 000 kW, but we have to put in 18 rotary-converter equipments, each of 2 000 kW, a total of 36 000 kW, or 6 times the generator power necessary in order to deal with this; and under the best conditions at any moment we may have only 3 of these substations in full operation and the other 15 idle. The efficiency of the rotary converters under such conditions would be extremely low. If, however, we employed single-phase locomotives (and assuming that we could operate at 11 000 volts), we could put in 3 static transformer substations, each to supply 36 miles of track and each of only 2 000 kW capacity, or a total capacity in static

transformer substations of 6 000 kW. Now, a static transformer is roughly one-sixth of the cost of a rotary converter plus static transformer and, as 6 times the total kilowatt capacity is required, it means that we shall be paying 36 times the price, in the case of the rotary converter substations, that we shall be paying in the case of the static transformer substations; the cost of the distributing feeders being about equal in the two cases. I was told by a prominent company which makes single-phase locomotives that the difference in efficiency between the single-phase locomotives and the d.c. locomotives, at full speed on the level, is only about 2 per cent. I would therefore strongly recommend either that we should not consider the question of main-line d.c. electrification solved until we can at least distribute at 3 000 volts (preferably 6 000), or, alternatively, that we should give a reasonable hearing to single-phase a.c. proposals.

Mr. R. G. Jakeman: The salient point of this paper is flashing-over, and the author describes very clearly what exactly happens when a flash-over occurs, and shows how it may be prevented. The idea of a fan to blow out the arc is very primitive, but there appear to be difficulties in applying it practically. It is not easy to make a rigid construction when the fan is mounted on top of the banding-wire. Further, if the armature winding has to be repaired, the fan must be removed. The magnetic blow-out is more scientific, and further details as to its action would be very useful. I take it that the magnetic flux is directed radially to the commutator, so that the arc is driven axially. Fig. 9 appears to show a fan as well as the blow-out. The author states that high-voltage rotary converters are not much larger than low-voltage converters, but it must be remembered that, in addition to the low space-factor in the slots, the cooling is also worse on account of the extra thickness of insulation. The output of the example given is 600 kW at 480 r.p.m., whilst present-day practice for lower voltages gives 1 500 kW at 500 r.p.m. It is interesting to note that a commutator speed of 8 000 ft. per min. has been found satisfactory. Although this is returning to the peripheral speeds used in turbo-dynamos, yet the centrifugal stresses in the case of the rotary converter are much lower, owing to the larger diameter. The speed of the commutator surface past the brushes is the same, but both brushes and brush-gear have been improved greatly since the day of the turbo-dynamo. With regard to telephone interference, the author describes the reasons for the ripples but mentions no remedies. The tooth-ripple can be reduced by making the number of slots as large as possible, in order to increase the frequency above those used on the telephone, and by employing a large air-gap under the main poles. Both these items tend to increase the dimensions of the machine. The pole-shoes may be skewed, and the number of bars in the damping winding must not clash with the number of slots. I do not agree with the author that the presence of a heavy damping winding causes ripples. The flux-linkage ripple can be largely reduced by using a large air-gap under the interpoles also, and the natural wave should be made as nearly sinusoidal as possible by suitably shaping the pole-shoe. The sixth-frequency ripple in Fig. 18 appears excessive and it would be of interest to have the analyses of the natural wave and the wave of the supply. It is remarkable that the d.c. voltage in Fig. 22 is almost smoother than in Fig. 18. It is to be regretted that the author did not use a differential method of obtaining the d.c. voltage curve, either by opposing a battery to the rotary converter or by connecting a condenser in series with the oscillograph. The paper is not intended as a comparison of the high-voltage d.c. and single-phase systems. That must be left to the Ministry of Transport, whose task is rendered easier by recent events, which have shown that British manufacturers are ready to undertake either system. However, looking at the paper broadly, and considering the difficulties which the author has shown to be inherent in the high-voltage rotary converter, I think that he has made out quite a good case for the single-phase system.

Mr. S. C. Bartholomew: I desire to deal only with that portion of the paper which refers to ripples and harmonics, as I am particularly interested in that from the telephone point of view. Years ago the direct-current system of traction, and in fact all direct-current supplies, were regarded as being harmless to the ordinary double-wire telephone circuit; it was the alternating-current system which was looked upon as the enemy. During the past few years, however, the position has been greatly modified, there being on the whole more trouble from d.c. than from a.c. systems. With the advent of the rotary converter the question of interference from direct current became a serious matter at one time, and I am pleased to hear that the author can now design rotary converters giving direct current with such insignificant ripples. The trouble with the rotary converter is due to two causes. The first is that it develops pronounced ripples at a frequency of between 900 and 1 200 per second, i.e. at frequencies which have the greatest effect on speech, the deleterious effect of a ripple of 1 100 per second frequency being something like 200 times as great as that of a 25-period ripple. The next reason is that the rotary converter is being used on an unbalanced power circuit, i.e. it is being used for traction and is usually therefore associated with an uninsulated rail return. The consequence is that these ripples become really important, which would not be the case if the rotary converter were used on an ordinary electric light system or power system where the conditions are balanced. The high-frequency ripple has very little effect on telegraphs, which are usually influenced only by those having a frequency between, say, 25 and 100 per second. It should be borne in mind that the telephone circuit is affected by a very few micro-watts, and I think that power engineers generally do not perhaps appreciate the fact that such slight currents may seriously disturb an important telephone circuit and that the effect is cumulative. A circuit which may be only moderately interfered with may be connected to others similarly disturbed, with the result that the combination circuit may be unfit for use. I am glad that the author has dealt with the question of ripples originating on the a.c. supply, and affecting the d.c. side. Some years ago tests on rotary converters were made at Dumbarton

under the direction of Dr. Magnus Maclean, and the oscillographs seemed to show quite clearly that the ripples originated solely at the rotary converter itself. Recently some tests were carried out by the Post Office on other machines in the North of England; in that case a rotary converter was proved to be practically perfect so far as ripples were concerned when run from the induction motor, and yet when run from the public supply certain harmonics were shown. Arising out of these tests a curious phenomenon came under notice which perhaps the author could explain. In these recent tests oscillograms were taken of the current in the positive and also the negative leads from a machine; these oscillograms showed that there was a definite and marked difference in amplitude between the ripples shown on the positive and those on the negative lead. The machine was supplying a tramway system at the time. The author states that it is possible to reduce the ripples to between $\frac{1}{2}$ and 1 per cent. If that can be done I think there is very little to fear from interference with Post Office circuits. In conclusion I would say that I consider the portion of the paper which deals with harmonics to be most valuable from the telephone point of view. The causes of many of the harmonics were known previously, but the presence of the sixth was difficult to account for and the author appears to have satisfactorily traced its origin. Dr. Smith said that it should be possible to design these machines to be free of harmonics, and needless to say this is very comforting to the telephone engineer. I trust that will be the ideal aimed at, now that designers realize that to ignore this feature may result in trouble to other interests.

Mr. J. K. Catterson-Smith (*communicated*): It would be interesting to have the author's opinion on the possible use of neutralizing windings for the prevention of field distortion under short-circuit conditions. I understand that such windings have been fitted to some large Continental rotary converters. During the development of the d.c. turbo-generator it was found that all methods of "boxing-up" the brush-gear on machines working at 20 volts per segment were quite ineffectual, and the complete solution of the flash-over problem was not obtained until neutralizing windings were fitted to the main poles in addition to the interpoles. Under any given conditions of load the converter armature ampere-turns result in an excess of d.c. reaction, but on short-circuits this reaction becomes very great with a sudden distortion of the field and consequently a rise in the voltage per segment. A neutralizing winding carrying the direct current could be fitted to compensate exactly the d.c. reaction, and this should assist in stabilizing the field during short-circuit. It appears that this remedy would be more effective in the case of a motor converter where the d.c. machine is operating partly as a d.c. generator, e.g. in the case of a 3 000-volt, 50-period motor converter. To conform with the limitations given by the author on page 502 the ratio of the poles in the induction motor to the poles in the d.c. machine would be given by the expression $f_2 = f_1[p_2/(p_1 + p_2)] = 50\,[1/(1 + 2)]$ $= 16\frac{2}{3}$ periods per second. With this ratio of poles two-thirds of the power would be dealt with by the d.c. machine as a converter, and one-third as a generator, with the result that the armature reaction would be largely a d.c. reaction lending itself to more perfect neutralization on short-circuit. The design of a 3 000-volt motor converter should be feasible on these lines, but naturally it would practically be that of a motor-generator. In connection with the quenching action of the air-blast upon flashing-over it may interest the author to know that in 1908 I constructed a small experimental 3 500-volt generator with 150 volts per segment working in compressed air at 200 lb. per sq. inch; the quenching action was so effective that it was impossible to maintain a flash-over. The author deals with harmonics in the applied voltage and in the supplied current and shows that the principal ripple to be expected is that giving 6 pulsations per cycle; I think it should be remarked that even under ideal conditions in which time-harmonics are absent there is still the possibility of the same pulsation frequency occurring, owing to the space-harmonics of the armature reaction ampere-turns. The fifth and seventh space-harmonics move at one-fifth and one-seventh synchronous speed relatively to the armature and, with opposite directions of motion, they reinforce each other and produce a pulsation 6 times per cycle in the main field and in the interpole field. I gather from the paper that little difficulty has been experienced in eliminating ripples due to these harmonics, presumably owing to careful arrangement of the damping grids and suitable effective width of the pole-shoes so that the ripples do not appear in the d.c. voltage.

Mr. J. M. Donaldson (*communicated*): The author has dealt very fairly with the question of traction supply by means of rotary converters from a 50-period system. In the London district, where 50 periods is the established frequency, it is, I believe, of the highest importance that railway electrification should be carried out from this system. At the Inquiry before the Commissioners in regard to the London district, some doubt was expressed as to the economy to be effected by giving supply for traction purposes and for general purposes from the same station and, although I am not in agreement with this, it has to be admitted that if traction supply is given at 25 periods and general supply at 50 periods, the economy in capital and running costs will not be of a very high order. Some 20 years ago, when the majority of electrical traction experience had been obtained in the United States, it was very freely stated that it was impracticable to give supply for traction (including tramway purposes) from 50-period rotary converters and, indeed, there were some grounds for this attitude at the time, the 25-period rotary converter of that time being infinitely better than the 50-period machine. The progress in rotary-converter design during the past 3 or 4 years is, I think, phenomenal, and the efficiencies actually obtained now would hardly have received credence at the commencement of that period. The 50-period rotary converter of to-day is many times better than the 25-period rotary converter of the early period I am mentioning, and, although this method of conversion to direct current is not by any means the only way available or necessarily even the best, there seems to be little

reason for railway engineers to refuse consideration of 50-period supply, more especially, of course, if they contemplate taking it from super-stations erected for general purposes. An ounce of practice is worth a ton of theory and the following particulars of what has been done in the past on traction service with 50-period rotary converters may be of interest. I refer to the system of the Metropolitan Electric Tramways which has been supplied through rotary converters at 50 periods from the commencement by the North Metropolitan Electric Power Supply Company. The majority of the machines were installed in the years 1904 to 1906 inclusive. There are at present operating eleven 250-kW machines, all installed in 1904 or 1905; three 500-kW machines installed in 1905 and 1907; and one 1 000-kW rotary converter of a more modern type, installed in 1913. There is no doubt that 250-kW machines are too small for a large system. The 500-kW machines have given excellent service, while the 1 000-kW machine, although of the interpole type, is not by any means of modern construction and has also given most admirable service. These 15 rotary converters, together with other rotary converters of a more modern type have, between the years 1904 and 1921, produced over 250 million kWh, and although, of course, it is not contended that the conditions of tramway supply are by any means as severe as those on heavy traction systems, yet, in view of the period of operation and the type of machine used, I think that the above figures might be considered to be a good testimonial for the 50-period rotary converter for traction work.

Mr. H. Hintermann-Brentano (*communicated*): In my opinion the best way to prevent flashing-over is to enclose the rotary converter in an airtight casing, and to replace the ordinary air by a compressed neutral gas or mixture of fluids, which should be kept cool and in constant movement.

Mr. P. Hunter-Brown (*communicated*): Mr. Cowie made a remark to the effect that the demand for a completely satisfactory slip-ring brush has not yet been met. This rather suggests that the performance of a brush is not influenced to any great extent by considerations beyond the brush itself. Doubtless Mr. Cowie did not intend his remark to convey this meaning, but unfortunately it does not appear to be sufficiently appreciated that the collecting of current from a slip-ring is a combined brush, brush-holder, and slip-ring problem. There are two rubbing surfaces, both of which must receive every possible attention in design and manufacture. Instances have been met where the results obtained on two rings of the same rotary converter have been radically different, and the good and bad rings have remained unaffected by an interchange of the two sets of brushes. The usual practice in slip-ring manufacture is to control the composition of the rings with more or less care and then to use them as cast without subjecting them to any special heat treatment, the result being that microscopically they exhibit a dendritic structure, the crystals having a very uncertain composition. It is believed that in practice the rings vary very largely and consist of hard crystals of γ or δ phase embedded in a softer α or $(\alpha + \beta)$ matrix, and that these hard crystals tear the brush contact-surface and prevent the formation of the smooth running surfaces necessary if the wear of both brushes and rings is to be reduced to a minimum. Preliminary investigations made on a number of different alloys suggest that heat-treatment of the rings is of greater importance than the chemical composition, or rather that the latter may be varied between quite wide limits, but that the rings must be suitably heat-treated after being cast, in order to obtain the best results. The composition of the ring must of course be such as to give a good, sound homogeneous casting as free as possible from oxides and minute blow-holes. Admiralty gunmetal (88 per cent copper, 2 per cent zinc, 10 per cent tin) has been found to be a very good mixture for the purpose, but perhaps could be improved by the addition of a little phosphorus (not exceeding, say, 0·3 per cent) to remove the oxides. The composition of this mixing is such that by a suitable heat treatment at about 700° C. an α or $(\alpha + \beta)$ structure can be obtained free from objectionable γ and δ crystals. The micro-photograph (Fig. B) shows a phosphor-bronze ring as cast (composition: copper 89·6 per cent, tin 10 per cent, phosphorus 0·36 per cent). Fig. C

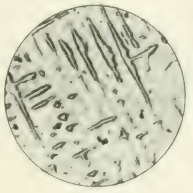


Fig. B

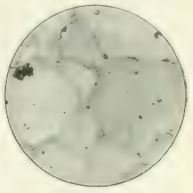


Fig. C

shows the same ring after heat treatment. The treatment in this instance reduced the average rate of wear of the brushes by 32 per cent and of the rings by 40 per cent. Much work remains to be done to determine the best time-temperature treatment for various sizes of rings and in the settlement of other details, but the results obtained indicate that the subject is one worthy of investigation. The function of the brush-holder is to enable the brush to maintain as intimate contact as possible with the rings which, in practice, can never be made mathematically circular. Every effort should be made to ensure that these are as truly circular as possible and are maintained in this condition. To this end it is important that the brush-holders be distributed correctly round the ring. Ring wear is due to three causes, i.e. mechanical abrasion, a burning action, and a quasi-electrolytic or arc effect which causes a transference of metal from the ring surface in the direction of current flow. From this it is obvious that, if the wear of the ring is to be uniform circumferentially, current must flow both to and from every portion of the ring running surface. If, say, a 4-pole rotary converter were equipped with only one brush per ring then, while two opposite quadrants of any ring were passing in turn under the brush, current would

always flow in the direction of, say, brush to ring, and, in the case of the other two quadrants, from ring to brush. Wear due to the third cause mentioned above would therefore occur on two alternate quadrants and not on the remaining two, thus causing two long " flats " to form, with the usual resultant cumulative troubles. If further brushes were added, all being concentrated under one pole, the result would be similar, but, if the brushes were distributed over the arc covered by an even number of pole pitches, or more particularly if they were distributed in pairs in such a way that the two brushes constituting a pair were 180 electrical degrees apart and the whole set on each ring were equally spaced, the conditions for promoting uniform wear would be as perfect as possible. Trouble of this description has been experienced and completely overcome by re-spacing the brushes as described.

Mr. G. Wüthrich (*communicated*): I should like to give a few details in regard to two 1 500-volt, 50-period machines of this type in operation in Switzerland. The rotary converters in question are each designed for 375 kW (one hour rating), 1 500 volts, and 50 periods, at 1 500 r.p.m.; they are working at present at 1 350 volts but were built for 1 500 volts and underwent exhaustive tests at the latter pressure. These machines were supplied by the Oerlikon Company for the Rosental substation of the Frauenfeld-Wil Railway in the North of Switzerland; this substation is, I believe, the first installation on the Continent to be equipped with 50-period rotary converters designed for such a high pressure. The machines are compound-wound, have 6 slip-rings, and are provided with special interpole windings of patent design. They start up from the a.c. side as squirrel-cage motors. All windings are insulated for the total pressure, and the frame of the machine is earthed. An interesting feature of the installation is the special type of circuit breaker used. This circuit breaker, which ensures instantaneous interruption of the circuit, is based upon a new principle, in that it is operated directly by the dynamic action of the current. It is, however, a notable fact that even with circuit breakers, not acting especially rapidly, 1 500-volt, 50-period rotary converters of the Oerlikon type have shown no tendency to flash over. On test, the machines started up with one-seventh of the normal pressure and reached full speed in 20 seconds; the starting current measured on the high-tension side of the transformers rose to only half its full-load value. The commutator brushes were not raised when starting up but, in spite of this, the sparking was so slight as to exclude any possibility of harmful effect. The machines were tested by the Hopkinson method; during these tests the load was put on and taken off suddenly without causing any disturbance on the machines. Short-circuiting tests were also carried out when the machines were running light, with full pressure across the terminals. A detailed description of this installation is given in the *Bulletin Oerlikon* (No. 6, December, 1921).

Mr. F. P. Whitaker (*in reply*): When considering the conversion of power from alternating current to 1 500 volts direct current referred to by Mr. Roger Smith, no doubt 25 periods is a convenient frequency from the machine designer's point of view. Although 1 500-volt rotary converters can be built for operation on 50 periods, I believe that such designs will result in a lower standard of operation than would be obtained with two rotary converters in series on 1 500 volts, without any gain either in efficiency or first cost. An alternative to two rotary converters in series is the motor converter, which is satisfactory for the generation of 1 500 volts direct current in one armature. The cost of two rotary converters in series with transformer would be approximately the same as that of a motor converter without transformer. The motor converter, however, is unsuitable for direct connection to a.c. voltages higher than approximately 11 000, so that in such cases additional expenditure and drop in efficiency would result from the installation of transformers. I believe that the short-circuit conditions on 1 500 volts will require special consideration, whichever type of plant is installed, and this will no doubt lead to the installation of machines of robust design.

For the generation of 3 000 volts direct current referred to by Mr. Cowie, I would advocate the synchronous motor-generator set. Such an equipment would consist of a synchronous motor coupled on either side to a 1 500-volt compensated d.c. generator, the two d.c. generators being electrically connected in series. An order has been received and the designs are at present being completed for eighteen 2 000-kW sets of this character which will be installed on the South African railways. The d.c. generators will be generally similar to that shown in Figs. 9 and 10 of the paper. With regard to the high-speed breaker, there is no doubt that the probability of a flash-over occurring due to a short-circuit can be materially lessened by reducing the time taken for the breaker to open the circuit, but the time of rupture of the arc must not be reduced to too low a value, on account of the possibility of producing voltage-rise. The successful operation of the high-speed breaker depends upon reducing the quantity of highly conducting vapour produced under short-circuit, so that, when the breaker opens and the voltage across the commutator is restored, there is less chance of the voltage striking through the vapour produced.

In reply to Colonel O'Brien, I would suggest that the improvement effected by cutting out the compound winding is connected with the stability of the machines and is not the result of reducing the instantaneous short-circuit currents. With regard to the mercury-arc rectifier, I think it will be found that the d.c. voltage is not so uniform, the d.c. voltage regulation is unsatisfactory, the high-tension power factor relatively low, and the wave-shape of current on the high-tension side poor. The time taken to start up the equipments mentioned by Colonel O'Brien would necessitate keeping a large amount of unnecessary plant in service, and recent experience would indicate that it cannot compare with the rotary converter in simplicity and reliability.

I agree with Mr. Juhlin that it is not impossible to construct 1 500-volt 50-period rotary converters with single armatures, but for the same initial cost I am doubtful whether such machines would have the same margin in operation or as high an efficiency as two machines

in series designed with correspondingly lower limits. I agree with Mr. Juhlin that reliability should come first. With regard to the limit of pressure per bar, I consider 15 to 16 volts per bar for 50-period work to be a little on the high side for 500- to 600-volt working, although good service may be obtained from machines designed with such constants under certain conditions of service. I think, however, that the figure should be decreased somewhat for 1 500-volt working. I believe we are all agreed that it would not do to push this limit too far, and it really becomes a question of just how far. Floor space would be gained, but it is doubtful if the single-armature converting unit would be the equal of the double-armature unit in any other respect. Mr. Juhlin and Dr. Smith mention the effect of the third harmonic current on the d.c. voltage wave. I think it will be found that if the third harmonic currents are plotted out in position at various time intervals, an armature reaction is produced which pulsates with regard to the armature conductors. This pulsating armature reaction may be split up into two components, one of which produces a constant change in the flux distribution over the pole-face. The other produces the variations referred to in the paper. I cannot follow Dr. Smith's remarks in regard to damping windings and field system, as the damping windings tend to reduce the pulsations whatever the frequency of the disturbing harmonic.

I think that Dr. Smith is a little optimistic concerning the ease with which 1 500-volt, single-armature 50-period rotary converters can be built, and the limits which would be involved, and I doubt if engineers undertaking the responsibility of design for large contracts for converting machinery would be willing to go so far. I cannot follow Dr. Smith's reasoning in connection with the turbo-generator, rotary and mercury-arc rectifier. It was partly because designers could *not* design large outputs at economical speeds required by the turbine that the d.c. turbo-generator was superseded by the a.c. generator and rotary converters; the flexibility of the high-tension a.c. generator, transmission, and rotary-converter unit finally sealed its doom. No doubt if ever the mercury-arc rectifier becomes as reliable and can offer characteristics as suitable for railway service as the rotary converter, it will become a competitor of all rotating converting apparatus, but progress in other directions should not be delayed because some new or rather revived development may be improved in the future. I have previously referred to leaving out the compound winding on the machines referred to by Colonel O'Brien. I do not think the maximum peaks of the short-circuit current would be materially affected by connecting the series windings either differentially or accumulatively, and generally it would be unsatisfactory to operate rotary converters on traction service with heavy peak loads with reverse series winding.

In reply to Mr. Wray, I think that the economical overload varies with the position of the substation. In large, central substations the average load is higher, but the peak loads are less than in substations situated in outlying districts where the duty mainly consists of starting perhaps one or two trains occasionally.

In reply to Mr. Highfield, the speed of the shutter and the time taken for the breaker to commence opening the circuit were as follows:—

Photo	Aperture of Shutter	Time taken for Breaker to commence opening Circuit
Fig. 7 ..	F. 64	0·05 sec.
Fig. 10 ..	F. 64	0·04 ,,
Photos shown in the discussion	F. 64. For the low-speed breaker	0·08 ,,
	F. 64. For the high-speed breaker	0·01 ,,

It was not suggested, as Major Taylor appears to think, that the middle point of the two machines in series should be earthed, but the negative pole of the equipment consisting of two machines in series. The paper was not intended as a basis of discussion on rival systems, and I think many more factors than those introduced by Major Taylor would have to be included before any conclusion could be drawn.

I do not agree with Mr. Jakeman in thinking that difficulties will be experienced with the fan, and the latter is always removed for shipment. I think that the photographs shown during the discussion at Birmingham clearly cover the other points in regard to blow-out raised by Mr. Jakeman. If ripples are reduced to the limits shown in the paper, I think we need not anticipate interference, and there will be little need for further remedies. If Mr. Jakeman takes oscillograms of several well-designed rotary equipments, he will find that the sixth-frequency undulation in Fig. 18 is not excessive, but representative. The natural wave is given in Fig. 17, and the supply wave was almost a perfect sine-wave. Referring to the last paragraph of his remarks, I do not think that Mr. Jakeman wishes to infer that any particular system is free from difficulties, for in that case it would be readily accepted by all. With regard to the question of flash-over being an inherent difficulty, I think I can state that the Shildon–Newport 1 500-volt rotary converters have never been out of commission from this cause, although they have stood a very large number of short-circuits in service, and in practically every case the service was restored by simply closing the d.c. breaker. The service given has been equal—if not superior—to that of a standard 600-volt system.

I am unable to account for the difference in amplitude of the disturbing ripple on the positive and negative sides of the machine referred to by Mr. Bartholomew. If the oscillograph shunts were placed in one particular feeder—either on the positive or the negative side rather than in the main leads of the machine—the fact would be easily explained by parallel paths of different inductance, but I understand that this was not the case.

In reply to Mr. Catterson-Smith, I know of no successful or useful method of employing compensating windings on rotary converters. They would, however, be of service on motor converters. Mr. Catterson-Smith will find the oscillations referred to included under "Load

Oscillations" and, so far as we can determine, they are of small magnitude.

Mr. Wüthrich describes an interesting machine and a difficult one to design, and experience will no doubt show whether such designs are robust enough to stand heavy railway service. It would have been interesting if Mr. Wüthrich could have given figures showing the effect of short-circuits on these machines.

Mr. Hunter-Brown's contribution is exceedingly interesting. Slip-ring conditions are relatively easy on 1 500-volt working, on account of the small current to be collected. I have found it very necessary on the modern highly rated machine to design slip-ring gear so that mechanical wear is reduced to a minimum and the electrical wear distributed evenly over the whole of the ring to avoid the formation of flats.

South Midland Centre, at Birmingham, 22 February, 1922.

Mr. R. A. Chattock: In the introduction the author refers to certain characteristics that converting apparatus for railway work should possess, and apparently puts efficiency before reliability. Supply station engineers look upon reliability as being of the first importance, and I think that railway engineers will adopt the same attitude. Reliability is closely connected with simplicity, as regards both installation and operation. I am convinced that it is better to sacrifice 1 or $1\frac{1}{2}$ per cent in efficiency if greater reliability and simplicity of operation can be obtained. The author refers to the periodicity as affecting the maximum d.c. voltage that can be generated in a rotary converter with a single commutator. It appears that with a periodicity of 50 the maximum d.c. voltage is only 1 000, whereas with a periodicity of 25 it is 2 000. It seems to me that this is a very important point in favour of 25 periods as compared with 50 periods, because, with double the voltage, the number of substations required will be very considerably reduced. The author gets over this disability to a certain extent by running two rotary converters in series, but this arrangement seems to detract very seriously from the important requirement of simplicity of operation. Such an arrangement is, in my opinion, too complicated—especially for automatic operation of the substations, which is practically a necessity in view of the heavy cost of labour that would be required in a number of non-automatic substations. The photographs illustrating the methods adopted for preventing flashing-over on the commutator on short-circuit show that this disability of the rotary converter has been very carefully taken care of, and it would be interesting to know if it proved to be satisfactory in all cases. As regards the use of high-speed circuit breakers, it seems to me that, with so much rotating plant on the system, consisting of the motors on the trains as well as the rotary converters themselves, there must be the risk of high-voltage surges due to self-induction when the breaker opens. These surges would be likely to break down the insulation on the system unless any special steps were taken to prevent them. I should like to know whether any such steps have been taken. On page 506 the author says: "The 25-period equipment has an advantage in efficiency on the lower loads, but not such as to warrant the installation of 25-period equipment if a material gain in generation can be obtained by the use of 50 periods." I should like to know what material gain in generation by the use of 50 periods is referred to. As far as I know, it is quite as efficient to operate a 25-period generating plant as a 50-period plant. The initial cost of such plant, however, might be heavier, although not to such an extent as really to affect the working results. On the other hand, as I have pointed out, the use of 25 periods has a distinct advantage in enabling a higher d.c. line voltage to be obtained with a less outlay on substations, and will reduce operating and maintenance costs. The author refers briefly to the use of automatic substations. In my opinion automatic operation will be a necessity for railway work, and from information which I have received it is evident that the initial cost of an automatic rotary-converter equipment is about double that of the ordinary equipment. I think that this will militate against the adoption of rotary converters when comparing their use with the mercury-arc rectifier, as it is quite possible to render the operation of the latter automatic with very little extra expense. I should like to hear the author's opinion in regard to the high cost of the automatic attachments.

Mr. F. Forrest: The paper appears at a very opportune time, in view of the decision of the Advisory Committee of the Ministry of Transport to recommend that 1 500 volts direct current be standardized for railway electrification in this country. In choosing substation plant, railway engineers will call for a type which, as far as our present knowledge goes, gives the maximum of reliability, simplicity, efficiency and safety for a minimum investment of capital. The author gives photographs of 1 500-volt rotary converters fitted with means for projecting the arc or flame away from the commutator in the event of a short-circuit occurring, but I think railway engineers will hesitate to install such machines, which it would be dangerous to approach when running on load. From Fig. 7 it is evident that it would be highly dangerous for an attendant to feel or examine the bearing at the commutator end, in case a short-circuit occurred at the time. The mercury-vapour rectifier is a much more desirable substation unit than the rotary converter for high-voltage traction purposes. It is more efficient, is cheaper in first cost, and having no moving parts it only remains to be proved that it is perfectly reliable for a period of years to become ultimately the recognized substation unit for railway service. If we bear in mind that the modern rotary converter is the product of 20 years' experience under all sorts and conditions of service, whilst the mercury-vapour rectifier in its present form has been on the market for only a comparatively few years, it is fair to say that its development has so far been very satisfactory. The maintenance of the proper vacuum is undoubtedly a problem, but as high-vacuum

pumps are now brought to a high pitch of perfection this difficulty is certain to be overcome. With regard to automatic substations, the cost of a fully automatic rotary-converter substation equipment is at present far too high. From figures I have recently examined it appears that the cost of a 300-kW rotary-converter unit arranged for automatic operation is almost exactly twice as great as that of the same unit arranged for manual control. It is difficult to see how this high cost can be justified. As the automatic substation will generally be called upon to run only a few hours per day, it is essential that its capital cost should be kept down to the minimum, even at the expense of efficiency, so that, even if mercury-vapour rectifiers are not ultimately chosen, it is possible that railway engineers may decide to install a simple induction motor-generator in substations arranged for automatic control.

Dr. M. L. Kahn: The principal point which must be considered in the design of rotary converters to be used on railways is the question of short-circuits. The short-circuit on a rotary converter is a transient phenomenon, and it is necessary to understand what happens at the various stages, so as to be able to appreciate and eliminate as far as possible the effects of the phenomenon. Let us assume a machine protected by a d.c. circuit breaker, which is not of the special high-speed type mentioned on page 506 of the paper. Such a breaker opens after roughly 0·05 second. Let us further assume that the a.c. breakers are set with time limits, so as to avoid disconnecting the machine from the a.c. supply. This is desirable in order to avoid the delay due to starting and synchronizing the rotary converter after it has been cut off from the a.c. supply. If a line short-circuit occurs on such a rotary converter the current flowing into this short-circuit rises rapidly at a rate equivalent to 100 to 400 times full-load current per second, so that after 0·005 second, corresponding to the time which a 50-period current takes to change from zero to its maximum instantaneous value, the current will increase to 5 to 20 times its normal full-load value. The rotary converter is a combination of a d.c. generator and a synchronous motor. An overload thrown suddenly on to the machine, due to the rapid rise in current, causes deceleration of the armature, so that a considerable part of the energy given out on the d.c. side is supplied by the moving masses of the armature, and not in the form of a.c. energy. In other words, the alternating current does not rise nearly as rapidly as the direct current. The commutating poles of rotary converters have to be adjusted to suit permanent running conditions, when the alternating and direct currents in the armature are practically balanced, and the armature reaction is comparatively small, e.g. only about $12\frac{1}{2}$ per cent of the armature reaction of a d.c. generator with the same number of armature bars carrying the same current. Under the transient conditions of short-circuit, where the direct current in the armature is not balanced by a corresponding alternating current, the armature reaction is greatly increased, and the commutating poles are practically put out of action unless special precautions are taken. This leads to violent sparking, i.e. heavy arcs between the brushes and the commutator, and copper-gas vapours are formed by these arcs round the commutator and act as a conducting medium between brush-arms of opposite polarity, and between brush-arms and unprotected earth paths. It must be understood that during short-circuit the difference of potential between brush-arms of opposite polarity is comparatively small, as they are practically short-circuited, while a very heavy voltage-drop takes place in the armature itself and under the brushes. It is therefore quite possible that no actual flash-over takes place whilst the short-circuit is on the machine. As soon as the d.c. circuit breaker opens and cuts the machine off the short-circuit, the heavy current on the d.c. side is interrupted. The voltage rises between brush-arms of opposite polarity and the copper vapour enveloping the commutator acts as a conductor between the brush-arms and causes the flash-over. A contributing factor to this flash-over is the unbalancing of alternating and direct current in the armature in the opposite direction to that described above. If the circuit breaker on the d.c. side opens, the d.c. load on the armature decreases and the armature is accelerated into a position relative to the field corresponding to this reduced load by taking a large amount of alternating current. The fact that the alternating current flowing in the armature is now much heavier than the direct current causes a considerable increase of armature reaction, and the commutating poles are again put out of action, whilst large E.M.F.'s are induced by the a.c. field in the coils short-circuited by the brushes. This again leads to violent sparking, and as the potential between the brush-arms is high, due to the fact that the machine is cut off from the short-circuit on the d.c. side, the machine will now flash over. The short-circuit on the d.c. side is thus re-established and, even if it is temporarily blown out, the sequence of events will be the same as described above, the blowing-out of the short-circuit corresponding to the opening of the circuit breaker. The phenomenon is similar to that of hunting, and flash-overs may occur in rapid succession until the machine is cleared on the a.c. side. The explanation of the phenomenon shows the great importance which is to be attached to the fan mentioned in the paper, which blows away the copper gas as soon as it is formed round the commutator. Magnetic blow-outs and flash guards are, of course, valuable further safeguards. The author has not, however, mentioned that it is desirable to fit such machines with very strong commutating poles, so as to avoid as far as possible the commutating poles being put out of action by the unbalancing of the alternating and direct currents in the armature.

Professor W. Cramp: While it must be agreed that the paper is a tribute to the author's skill and enterprise, it appears also to demonstrate that the rotary converter is very ill-fitted for d.c. railway work, for if it is entirely unsuitable for 3 000 volts and 50 periods, and if above 33 periods it is necessary to connect two machines in series, then the motor converter would seem to be far better fitted for the service demanded, since it requires no transformers, has much better brush spacing for the same peripheral speed,

fewer field poles and better control of d.c. voltage and a.c. power factor. The author omits all mention of the transformers and their connections, which are an essential part of the equipment. For instance, do the efficiency and power-factor curves shown in Fig. 12 include the transformers or not? If they do not, the maximum efficiency obtained will not be very high when transformer losses are allowed for, although the general characteristics of the machine shown in these curves are very good. The photographs showing short-circuit phenomena are very striking, but the scale of ordinates in Fig. 11 should be added and a further explanation of the arcing tips mentioned on page 505 is desirable. Can the author say whether the arc can ever exist on a commutator apart from the brush-holders? Fig. 13 I take to be merely of academic interest, since the conditions supposed can never exist in practice. The author gives too few technical data to enable his oscillation limits to be criticized. He does not, for instance, give any details of slots and teeth, or of pole shoes or of magnetic densities. In any case I cannot see how a distinction can be drawn between flux pulsation and flux swinging, and I should be glad if the author would explain what he means in this connection; and what is meant by saying that reactance tends to keep the tooth oscillation up. Also, what does he mean when he says that the tooth ripple need not exceed $\frac{1}{2}$ per cent of the "voltage ripple"? Which voltage ripple is referred to? A distinction should be drawn between telephone disturbance due to ripples on the a.c. mains and those due to the d.c. feeders. I understand that in this country it is proposed that railways should use underground cables for alternating current, which will obviate the former ripples; and the latter I think could be avoided by the use of reactance on the d.c. side. Has the author tried this? It would have a secondary beneficial effect, viz. that on short-circuit the interpoles would be more effective, since the alternating supply current and its armature reaction would be more nearly in phase with the current changes on the d.c. side. By recent experiments at Birmingham University we have found that the ripples on the tramway supply system due to the rotary-converter commutators are negligible compared with telephone disturbances set up by the tramcar motors, and these latter would be more pronounced in railway work where the motors are relatively so much larger. We found that these disturbances were probably due quite as much to tooth flux as to any other cause. I am glad that the author calls for a more precise standard for alternator generator wave-shape, and I should like to know whether his firm has brought this matter to the notice of the B.E.A.M.A.

Major A. M. Taylor: The author has made progress which I believe is distinctly in advance of what has been achieved in America, judging by information given in the February issue of the *Electric Journal*. It appears that in America, on a 500-kW rotary converter of ordinary construction wound for 600 volts, the flash-over occurred at about $5\frac{1}{2}$ times full-load current. A similar converter was provided with commutating poles having a high magnetic reluctance, in order to keep the commutating flux tolerably constant through the wide ranges of fluctuation of the current when the machine is on short-circuit, or when the short-circuit is opened by the circuit breakers. The result of this improvement was to increase the flash-over point to 9 times the normal full-load current of the machine without any external protection in the form of high-speed switches. I gather from Fig. 4, however, that the author has successfully caused his 600-kW 750-volt converter to carry up to 19 times full-load current before it flashed over, and when the flash-over did occur there was practically no damage done to the commutator, which, I gather, was not the case in the American tests. On the other hand, the English tests were taken on a machine at 40 periods, while the American tests were taken at 60 periods, which presumably means that the American figure of 9 times should be credited with $13\frac{1}{2}$ times in comparison with the English machine. This latter figure must, however, again be discounted on account of the voltage of the English machine being 750 as against 600, so that probably 11 times full-load current would be a representative figure. This, as compared with the figure of 19 times obtained by the author, speaks for itself, and is testimony to the very fine result he has achieved. In another American machine fitted with the high-reluctance commutating pole but protected externally by a high-speed circuit breaker, the machine when on short-circuit reached a current of only 6 000 amperes, but behaved excellently. This was apparently only some 3 times the normal full-load current of the machine (1 500 kW) and therefore it might have been expected that any machine however poor would have behaved equally well. I think that the author is on the safer side in not depending exclusively upon external control, because the flash-over can take place perfectly well across the commutator (and in fact does so) *after* the external switch has operated. It is therefore very much better for the machine to be self-protective if possible, and this result would seem to be secured by the author's arrangements.

Mr. F. W. Carter: The paper is of great interest to those engaged on electric railway engineering, for the rotary converter, within its limits, is still foremost among substation units, and shows no sign yet of yielding to any rival. The author has indicated limits of voltage and frequency, but it is doubtful whether railway engineers generally will be prepared to go with him to the ultimate limits. I note that the rotary converters mentioned in the paper are generally six-phase, and I should like to ask the author whether he has ever considered the twelve-phase rotary converter, which can, equally with the six-phase converter, be run from a three-phase circuit. The twelve-phase rotary converter at unity power factor has an armature loss of 21 per cent of that due to the direct current alone, whilst the six-phase rotary converter has a loss of 27 per cent. The loss in the coils next to the taps is 18 per cent greater than the mean in the twelve-phase rotary converter, against 57 per cent in the six-phase machine. Moreover, the reactance voltage is more uniform so that the conditions for commutation are better. Against these advantages must be set

the disadvantages of having 12 slip-rings instead of six. The figures given above are theoretical and do not take account of parasitic losses, which are apt to be greater in a rotary converter than in a d.c. generator. The armature current in the latter is of a square-topped wave-form, which can be expressed as a fundamental with a series of harmonics; and the harmonics are chiefly the cause of the parasitic losses. In the rotary converter the fundamental is largely annulled by the alternating current, so that the harmonics are relatively of greater importance and the parasitic losses are therefore greater for the same depth of bar. The author discusses very fully the question of the oscillations which may be imposed on the line by the operation of a rotary converter. The mercury-vapour rectifier has been mentioned, and it would be interesting to know whether the sharp variations of current in this apparatus do not in a measure reach the line and cause serious interference with neighbouring telephone circuits.

Mr. F. P. Whitaker (*in reply*): I agree with Mr. Chattock's remarks on reliability. I do not think, however, that the limit of voltage per commutator will affect the number of substations. No harm will result from reducing the time taken for the circuit breaker to open the circuit, but undoubtedly the arc should not be quenched too rapidly. In cases where this is likely to occur, the high-speed breaker has been arranged to open on a resistance, but I believe that finally this result will be accomplished entirely on the breaker. If special stations, transmissions, etc., were required on 25-period electrification, then it is possible that the "all in" cost of generation would be higher.

In reply to Mr. Forrest, 1 500-volt apparatus will be treated as high tension, and will be suitably guarded when running under load conditions. The particular machines shown in photographs during the discussion were fitted with bearing relays, so that there will be no need for an attendant to take the risk suggested. I do not think that experience up to the present in England has shown the mercury-arc rectifier to be as reliable as the rotary converter on 400- to 600-volt service, and much remains to be done in connection with 1 500-volt working. It is unnecessary for me to enter into the relative merits of these two classes of apparatus, as such a comparison has been published in the monthly survey of the *Beama Journal*, February 1922. I do not think the rectifier possesses many of the good characteristics of the rotary converter. Automatic substations were developed abroad where the cost of labour was high; in fact this was an incentive to their development. I think that the cost of such equipments will reach a reasonable figure so soon as they are designed, manufactured and installed in this country on a reasonable basis.

An order is at present being completed for eight completely automatic equipments, each equipment consisting of a 1 000-kW, 500-r.p.m., 1 500-volt, 50-period rotary converter. An order has also just been received for the complete automatic control of eighteen 2 000-kW synchronous motor-generator sets for operation on the 3 000-volt railway electrification of the South African railways.

Dr. Kahn has clearly amplified the portion of the paper dealing with short-circuits, and his remarks are very interesting.

In reply to Prof. Cramp, I would say that each type of equipment has its limitations, and I think these have been clearly stated in the paper. Within those limits, no doubt, the rotary converter is well-fitted and not ill-fitted for railway work. The curves referred to in the paper include transformers. I think Prof. Cramp will find the scales given in Fig. 11. The arcing tips were extensions to the commutator bars, the extensions being rather thinner than the corresponding bars. There was an air space between the extensions. This construction was adopted to prevent the mica being damaged on the surface, just where the arc is finally broken on the commutator. In the case of a high voltage per bar, I think that a flash can start round a commutator irrespective of the brush-holder, but tests indicate that, providing the voltage per segment is reasonable, the flash is generally caused by the copper vapour produced by the arc drawn out from the brushes while the machine is under short-circuit. I do not know of any reason why Fig. 13 cannot exist in practice. With regard to the part of the paper dealing with telephone interference, from time to time interference has resulted on systems fed from rotary converters. With a view to preventing such occurrences in future, an investigation of the causes of ripples and undulations in the d.c. voltage was undertaken, and the findings and conclusions are given in this paper. Actually, in practice, flux-swinging may be produced without appreciable flux pulsation, and flux pulsation may result without appreciable flux-swinging being present. The word "ripple" was inserted in error.* The sentence should read "$\pm\frac{1}{2}$ per cent of the d.c. voltage." The ripples may be suppressed to a considerable degree by means of a resonant shunt or modifications of the resonant shunt, but I do not think that reactance by itself would prove very satisfactory in service. The tooth ripple on tramways motors is a possible cause of interference, but this was not mentioned as it was really outside the scope of the paper.

In reply to Major Taylor, it is always a little difficult to compare tests on machines built in different countries, unless very complete particulars are given. I think it will be found that there is no need to go outside this country in order to obtain highly developed and robust machines.

Whenever the question of 12-phase versus 6-phase mentioned by Mr. Carter has been investigated, I have never been able to find the former arrangement economical. I think that the undulations on the line are likely to be more serious with rectifiers than with rotary converters.

* Corrected for the *Journal*.

REPORT OF THE COUNCIL PRESENTED AT THE ANNUAL GENERAL MEETING OF 25 MAY, 1922.

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REPORT.

The Council, at the Fiftieth Annual General Meeting of the Institution of Electrical Engineers, present to the members their Report for the year 1921–22, covering approximately the period 1 April, 1921, to 1 April, 1922.

The Council have continued to receive evidence of the value attached to the work of the Institution both by the membership and by other societies and bodies with whom the Institution is in touch.

The Council gladly again refer to the generous devotion by members of the Institution of their time and expert knowledge to the work of its various Committees.

(1) Royal Charter.

The Council here record with great pleasure the granting of a Royal Charter to the Institution on the 15th August, 1921.

With equal pleasure, they also record that His Majesty King George has graciously consented to be Patron to the Institution.

(2) Bye-Laws.—New Seal.

Bye-Laws for the Chartered Institution were approved at a Special General Meeting of Corporate Members held on the 23rd March, 1922, and are now awaiting the sanction of the Lords of the Privy Council.

In accordance with the Charter, a new Seal has been provided for the Chartered Institution and has been in use for some time.

(3) Liquidation of Old Institution.

At Special General Meetings of Corporate Members and Associates held on the 17th November and 2nd December, 1921, the Honorary Treasurer (Sir James Devonshire, K.B.E.) and the Secretary (Mr. P. F. Rowell) were appointed liquidators for the purpose of winding up the old Institution and, after the satisfaction of its debts and liabilities, transferring its remaining property to the Chartered Institution.

The liquidators have taken the various legal and other steps necessary to give effect to their mandate and a final meeting of the members of the old Institution will shortly be held for the purpose of dissolving it.

(4) Membership of the Institution.

The changes in the membership since the 1st April, 1921, are shown in a table which will be found in Appendix A.

The continual growth of membership is emphasized by comparison with the corresponding totals for the last few years, which were as follows :—

Year	Membership	Increase or Decrease
1913	7 084	— 547
1914	7 045	— 39
1915	6 811	— 234
1916	6 676	- 135
1917	6 613	— 63
1918	6 667	— 54
1919	7 023	- 356
1920	8 146	— 1 123
1921	9 449	— 1 303
1922	10 275	— 826

It will be seen that the average annual increase of membership for the last three years is over 1 000, and the Council have again to express their gratification at this rapid growth, notwithstanding the increasing stringency of the qualifications for admission.

(5) Associate Membership Examination.

The Examination was held in April and October, 1921, at home in London, Cardiff, Chatham, Chelmsford, Manchester, Newcastle-on-Tyne, Prescot, Southampton, Stoke-on-Trent and Swansea, also abroad in New Zealand and at Buenos Aires. The candidates examined included a number of officers of the Corps of Royal Engineers who sat for the examination for the purpose of qualifying for "Engineer Pay."

A certain number of candidates submitted theses and papers during the year in lieu of the examination.

(6) Honorary Member.

The Council have pleasure in recording that, as announced at the Ordinary Meeting of the 17th November last, they have elected The Rt. Hon. Lord Southborough, P.C., G.C.B., G.C.M.G., G.C.V.O., K.C.S.I., to be an Honorary Member of the Institution.

(7) Honours and Distinctions Conferred on Members.

Since the last Annual Report the following honours have been conferred on members :—

K.B.E.

Larke, W. J., C.B.E. (Member).

C.I.E.

Meares, J. W. (Member).

Legion of Honour, Officer.

Stevens, Major E. J. (Associate Member).

Order of Leopold, Officer (Belgium).

Ditmas, Lieut.-Col., F.I.L., D.S.O., M.C. (Associate).

Military Order of the Sacred Treasure (Japan).

Ditmas, Lieut.-Col., F.I.L., D.S.O., M.C. (Associate).

Médaille du Roi Albert (Belgium).

Dykes, A. H. (Member).

(8) Deaths.

The Council have to deplore the death of 54 members of the Institution during the year.

Members.

Carpentier, J.
Coates, E.
Crocker, Prof. F. B.
Fox, Sir Douglas.
Gibson, G. H. L.
Hart, F. G.
Hopkinson, Dr. E.
Newington, A. G.
Sclater, A. W.
Slacke, R. B.
Sloog, H.
Smith-Cleburne, F. W.
Suenson, Commodore E.
Topping, F. W.
Unwin, A. H.
Wilkinson, J.
Winkfield, R. E.

Associate Members.

Alexander, D. J.
Baker, J. E. R.
Boyd, W. B.
Browne, W. S.
Clark, Alexander.
Connal, A. R.
Hall, A. C.
Hutchings, A.
James, T. L.
Lamb, B. H.
Milton, John.
Myles-Hook, R.
Phillips, Major J. H. S.
Radforth, W. E.
Rae, B. G.
Reath, W. E.
Taylor, C. E.
Temple, M. G.
Webster, J. M.

Graduate.

Lauwers, R.

Students.

Baker, F. L.
Bamford, J.
Clark, R. L. C.
Crabb, L. S.
Ellams, W. J.
Lodge, W. M.
Waterhouse, L. O.

Associates.

Barker, W. E.
Braulik, G. V.
Clark, T.
Poynton, W. A.
Rance, B.
Robertson, R.
Selwyn, G. A.
Tyler, Col. H. E.
Wilson, Charles.
Woollcombe, Dr. R. L.

The Council desire to make particular mention of the loss of such distinguished members as Mr. J. Carpentier (Past-President of the Société Française des Electriciens), Professor F. B. Crocker (Past-President of the American Institute of Electrical Engineers), Dr. Edward Hopkinson (Chairman of the North-Western Centre, 1900–1901, and Member of Council, 1892–4 and 1907–10), and Mr. R. E. Winkfield (Chairman of the Calcutta Centre, 1913–14).

(9) War Memorial.

The Council have had under consideration several schemes for a War Memorial to be erected in the Insti-

tution building, and a design for two bronze tablets to be placed in the entrance hall has been approved.

The War Memorial Book containing the biographical notices and portraits of members who fell in the War is now in an advanced state of preparation. The editing of the book, kindly undertaken by Lieut.-Colonel W. A. J. O'Meara, C.M.G., has entailed considerable correspondence and research with a view to the work being a complete and accurate record, and the Council desire to express their appreciation to the editor who has already devoted much time and labour to his task.

(10) Institution Building.

The Institution returned to its own building on the 17th May, 1921.

The Council were highly gratified at being able to place the Lecture Theatre and rooms of the Institution at the disposal of the Electricity Commissioners for the purpose of holding the London and Home Counties Electricity Supply Inquiry which lasted from the 14th June to the 29th July.

During the year the Council granted the use of the Institution Theatre and rooms to a number of allied and kindred societies.

(11) Wireless Aerial on Institution Building.

On the recommendation of the Committee of the Wireless Section, a permanent aerial has been erected on the Institution building. The dimensions are as follows:—

Span between strain insulators	113 feet.
Down-lead from aerial to leading-in insulator (outside)	63 feet.
Down-lead from leading-in insulator to floor of Lecture Theatre	44 feet.
	107 feet.
Effective length of aerial—	
Down-lead plus $\frac{1}{2}$ span	163·5 feet.
Natural wave-length (approximately) ..	200 metres.

(12) Meetings and Papers.

A statement of the total number of meetings and conferences held during the past twelve months, and of papers read, lectures, etc., will be found in Appendixes B and C to this Report.

(13) Premiums.

The following premiums for papers have been awarded by the Council:—

The Institution Premium (*value* £25).

J. G. Hill. "Phantom Telephone Circuits, and Combined Telegraph and Telephone Circuits, worked at Audio Frequencies."

The Ayrton Premium (*value* £10).

L. H. A. Carr, M.Sc. (Tech.). "Induction-type Synchronous Motors."

The Fahie Premium (*value* £10).

E. S. Byng. "Telephone Line Work in the United States."

The John Hopkinson Premium (*value* £10).

F. P. Whitaker. "Rotary Converters, with special reference to Railway Electrification."

The Kelvin Premium (*value* £10).

R. Torikai. "Abnormal Pressure-rise in Transformers, and Its Remedy."

The Paris Premium (*value* £10).

J. A. Kuyser. "Protective Apparatus for Turbo-Alternators."

A Premium (*value* £10).

F. J. Teago. "Test-Results obtained from a Three-phase Shunt Commutator Motor."

A Premium (*value* £5).

J. Anderson. "Electric Motor Starters."

A Premium (*value* £5).

W. Wilson, B.E., M.Sc. "Some Notes on the Design of Liquid Rheostats."

Wireless Section Premiums.

Duddell Premium (*value* £20).

T. L. Eckersley, B.A., B.Sc. "An Investigation of Transmitting Aerial Resistances."

A Premium (*value* £10).

E. B. Moullin, M.A., and L. B. Turner, M.A. "The Thermionic Triode as Rectifier."

A Premium (*value* £10).

C. S. Franklin. "Short-wave Directional Wireless Telegraphy."

The Williams Premium.

The triennial award of the Willans Premium falls to the Institution on this occasion and the Council have awarded it to Mr. K. Baumann for his paper entitled "Some Recent Developments in Large Steam Turbine Practice," read before the Institution 7th April, 1921.

(14) Commemoration Meetings.

In commemoration of the fiftieth anniversary of the first Ordinary Meeting of the Institution (then the Society of Telegraph Engineers) on the 28th February, 1872, a highly successful series of meetings was held on the 21st, 22nd and 23rd February, 1922, the proceedings at which were of considerable interest to many members of the general public. A full account will be published in a Special Commemoration Number of the *Journal*.

It was a matter of deep regret to the Council that the President, who had taken a leading part in making

the arrangements for the meetings and had devoted a large amount of time and consideration towards making them a success, was, owing to indisposition, unable to be present at any of the meetings.

(15) National Electrical Convention.

The Council have approved a suggestion made to them that a National Electrical Convention be held under the auspices of the Institution. At the time the Council approved the suggestion, it was thought that the first Convention might be held in connection with the British Empire Exhibition which was to have taken place in 1923, but in view of the postponement of the Exhibition to 1924, the Council will reconsider the question of the date for the first Convention.

(16) Ordinary Meetings.

The interest shown by members in the papers read and the discussions thereon has been greatly increased by the fact that the meetings are once more being held in the Institution's own premises.

The attendances during the past year have been uniformly large, and the cinematograph films of electrical apparatus and phenomena exhibited on three occasions proved an attractive feature.

(17) Local Centres and Sub-Centres.

The attendances reported at the Meetings held at the Local Centres and Sub-Centres afford similar evidence of the interest taken by members outside London in the work of the Institution.

During the Session the President paid visits to the Centres at Birmingham, Cardiff, Leeds, Manchester and Newcastle, and to the Sub-Centres at Loughborough, Liverpool and Sheffield.

The Council regret to put on record the discontinuance of the Aberdeen Sub-Centre on account of the small number of members in that district.

(18) Summer Meeting.

The Summer Meeting in Scotland which had to be postponed last year on account of the coal strike, will take place from the 30th May to the 2nd June, 1922, and will include lectures, visits to works, etc., and an excursion to the West Highlands.

(19) Wireless Section.

The Wireless Section of the Institution has held seven meetings, the first being occupied by the Address of the Chairman, Professor G. W. O. Howe, D.Sc. Seven papers were read at the other six meetings.

(20) Informal Meetings.

Ten meetings have been held, and the scope of the subjects discussed has been considerably widened this session. The attendances have been uniformly good, being from 80 to 100 at each meeting.

The Committee analysed and reported to the Council on the various suggestions made at the meeting held on the 24th January, 1921, to discuss in what ways the Institution could be made more useful to its members. This report was considered by the Council, and a number of the recommendations put forward by the Committee as a result of that meeting were approved, and put into force.

The comfort and convenience of meeting in the Institution's own building have much facilitated the work of carrying on the Informal Meetings, while the atmosphere of informality has been maintained.

The Council are highly gratified at the success of these meetings and congratulate the Informal Meetings Committee on their excellent work.

(21) Students' Sections.

The number of Students on the Register of the Institution has reached a record total of 2 455. A very full programme of meetings, visits to works, and social functions was carried out during the Session by the six Students' Sections now in existence, viz. in London, Birmingham, Glasgow, Liverpool, Manchester and Newcastle. The Council have recently granted permission for the formation of Students' Sections at Leeds and Sheffield. The latter Section has held two meetings.

Addresses to the London Students' Section were given by the President (Mr. J. S. Highfield) and Sir Philip Dawson.

A Students' tour in Switzerland, organized by the London Students' Section, took place towards the end of July, 1921. The following works were visited: Maschinenfabrik Oerlikon, Messrs. Sulzer Bros., and Messrs. Escher, Wyss & Co., at Zurich; Messrs. Brown, Boveri, at Baden; the Meiringen Carbide Factory; the Hydro-Electric Station at Spiez; the locomotive sheds of the Swiss Federal Railways at Berne; and the Mühleberg Hydro-Electric Station.

The Council cordially thank the firms named, owners of works, etc., for the courtesy shown by them on the occasion, and for the facilities afforded, which helped very materially in making the visit an acknowledged success.

The Council wish also to thank Mr. J. H. Reyner (Hon. Secretary, London Students' Section) for his valuable work in organizing the visit.

(22) Scholarships.

The following Scholarships have been awarded by the Council:—

David Hughes Scholarship.

(Value £50; tenable for one year).

W. T. Slater (College of Technology, Manchester).

Salomons Scholarships.

(Value £50; tenable for one year).

G. R. A. Murray (King's College, London).

P. G. A. Voigt (University College, London).

War Thanksgiving Education Research Fund (No. 1).

A grant of £100 for educational purposes has been made this year by the Council under the provisions of the Trust Deed to:—

J. D. Cockcroft (College of Technology, Manchester).

(23) Conversazione.

The Annual Conversazione was held at the Natural History Museum, South Kensington, London, on the 30th June, 1921, and was attended by over 1 600 members and guests. The Council were highly gratified by the presence at this Conversazione of the following delegates of American Engineering Societies :—

Mr. Ambrose Swasey (Head of delegation),

Mr. Robert A. Cummings, Dr. F. B. Jewett,
Colonel A. S. Dwight, Mr. William Kelly,
Mr. John R. Freeman, Mr. Charles T. Main,
Dr. Ira N. Hollis, Mr. Charles F. Rand,
Mr. Jesse M. Smith,

who brought to the gathering a cordial message of goodwill from the following Societies :—

The American Society of Civil Engineers,
The American Society of Mechanical Engineers,
The American Institute of Electrical Engineers,
The American Institute of Mining Engineers.

(24) Annual Dinner.

The Annual Dinner was held at the Hotel Cecil, London, on the 21st February, 1922. The members and guests present numbered 482. On this occasion, a message of congratulation was received from H.R.H. the Duke of York, and among other distinguished guests were the following who spoke : the Rt. Hon. F. G. Kellaway, Air-Marshal Sir H. M. Trenchard and Mr. Justice Sargant.

(25) Local Honorary Secretary for France.

In July 1921 the Council received with much regret from Mr. R. V. Picou his resignation of the office of Local Honorary Secretary for France, which he had held since 1911, and now tender to him the best thanks of the Institution for his valuable services. In his place the Council have appointed Mr. J. Grosselin, who will be remembered by many for the active part he took, as immediate Past President of the Société Française des Electriciens, in entertaining the members of the Institution who participated in the visit to Paris in 1913.

(26) Return Visit of Dutch Engineers.

The return visit of Dutch Electrical Engineers, the arrangements for which were reported in the last Annual Report to be in hand, duly took place from the 23rd to the 28th May last. The party consisted of the following representatives of the Royal Dutch Society of Engineers and of the Association of Managers of Dutch Electricity Undertakings :

Mr. J. G. Bellaar Spruyt (President, the Association of Managers of Dutch Electricity Undertakings), Managing Director, Stroomverkoop Maatschappij, Maastricht.

Mr. G. J. F. Bakker (Secretary, the Association of Managers of Dutch Electricity Undertakings), City Electrical Engineer, The Hague.

Mr. C. Noome (Second Secretary, the Association of Managers of Dutch Electricity Undertakings), Managing Director, Provinciale Utrechtsche Electriciteits Maatschappij, Utrecht.

Mr. E. van Dijk, Managing Director, Provincial Electriciteits Bedrijf in Friesland, Leeuwarden.

Mr. E. B. van Doesburgh, City Electrical Engineer, Groningen.

Mr. H. Lohr, Managing Director, Provinciale Electriciteits Maatschappij, Arnhem.

Mr. J. C. van Staveren, Manager of the Office for High-tension Lines, Maastricht.

Dr. W. Lulofs, City Electrical Engineer, Amsterdam.

Mr. A. B. van Hamel, Consulting Engineer to the Ministry of Commerce, Department of Economics, The Hague.

After being shown over various places of interest in London, the visitors travelled by motor via Henley, Oxford, Hereford and Chester, to Manchester which was reached on the 27th, the party returning to London by train on the 28th. The Council have since received a most cordial expression of thanks from the visitors for the hospitality extended to them by companies, municipalities and private hosts during their visit. A full account of the visit was published in *Institution Notes* for June 1921 (No. 27, page 26).

(27) Library.

After a period of over four years, the Institution and Ronalds Libraries were again accessible to members last summer, and the number of readers from September, 1921, to March, 1922, inclusive, was 1 202, of whom 52 were non-members. The highest number of readers for a complete year was in 1915–16 when 1 651 attendances were recorded.

The Council in response to a proposal made by several members at an Informal Meeting, decided to keep the Library open on two evenings each week until 9.30 p.m. or alternatively one evening a week and on Saturday afternoons until 5 p.m. In order to ascertain which days were most favoured by members, the Library was kept open every weekday evening and every Saturday afternoon from the 14th November to the 31st December, 1921. The experiment showed that the Library was used on the evenings on which Institution meetings were held and not to an appreciable extent at other times. Consequently the Council have decided to keep the Library open on the evenings on which Ordinary Meetings of the Institution, Informal Meetings and Meetings of the Wireless and Students' Sections are held.

During the year 251 books and pamphlets have been presented to the Reference Library by members and others.

Owing to the growth of the Library during the past few years it has been found necessary to increase the shelving accommodation, and for this purpose eight large double-sided book-presses have been provided between the Library windows.

It is with pleasure that the Council have to report the growing increase in the circulation of the Lending Library. During the year 1 450 books were issued to

564 borrowers, the corresponding numbers in the previous year being 818 and 408 respectively. The revised edition of the Catalogue which was issued in 1920 may be obtained on application to the Secretary.

(28) Museum.

The following objects have been presented during the past year and the Council desire to express their best thanks to the donors :—

List of Apparatus.	*Presented by*
The original induction motor invented by W. Baily, M.A., in 1879.	Professor F. G. Baily, M.A.
A large framed engraving of distinguished men of science of the early 19th century.	F. W. Carter.
A coil of the first 10 000-volt, 1 000-kW Ferranti dynamo.	G. W. Partridge.
A 25-light Ferranti transformer for 2 500-volt overhead system.	G. W. Partridge.
Specimen of overhead 61/17 cable designed for working pressure of 10 000 volts, 1889.	G. W. Partridge.
Specimen of Ferranti concentric paper-insulated cable, laid 1889–1890 for working at a pressure of 10 000 volts.	G. W. Partridge.
A 2 500-volt fuse block and fuse as used on overhead system of supply from Grosvenor Gallery, 1887–1890.	G. W. Partridge.
Four early lampholders.	F. H. Nalder.
An early Ediswan 10-kW dynamo.	R. W. Paul.
A collection of framed and unframed photographs of the Electric Lighting Station installed at Paddington in 1885.	A. H. Walton.
Four early incandescent lamps, 2 lampholders, a 2-way switch and a box-wood ceiling-rose.	A. H. Walton.
Specimen of a supply cable, "Gordon's divided main," showing a fault, Nov. 14th, 1885.	A. H. Walton.
An early a.c. ammeter, 1884.	A. H. Walton.
A Nernst lamp.	C. J. Wharton.

The Museum Committee have under consideration a scheme for the better exhibition of the apparatus in the collection.

(29) Electrical Appointments Board.

The Electrical Appointments Board report a substantial increase in the number of unemployed members who have placed their names on the Register. The number of names is now 120 as against a total of 51 last year.

The Council earnestly hope that firms having vacancies to fill will assist them by reporting these vacancies to the Secretary of the Board at the Institution offices.

(30) The Journal of the Institution.

The number of pages in the 1921 Volume was 852, as compared with 944 in 1920. In addition, a Supplementary Volume of 336 pages was printed in 1920, making a total of 1 280 pages for that year. The net cost of printing and publishing the *Journal* in 1921, after allowing for sales, was £4 936, as compared with £6 739 (including the cost of the Supplement) in 1920.

There has been a decrease in the cost of paper and printing, but this has been partially offset by the larger number of copies printed, necessitated by the rapid growth in the membership.

Owing to the trade depression of the past twelve months, the publication in the *Journal* of the Classified Index of British Manufacturers, to which reference was made in last year's Report, has been delayed, but a preliminary issue will appear at an early date.

(31) "Science Abstracts."

The Physics volume of *Science Abstracts* for 1921 contained 136 more pages than that for 1920, and the Electrical Engineering volume 16 more pages.

The contribution of the Institution towards the cost of publishing *Science Abstracts* in 1921 was £978, as compared with £261 in 1920, but the average for the two years was approximately the same as the average annual contribution since its conception in 1898. Among the causes which contributed to this increase were the higher rates of postage in force, the publication of a larger quantity of matter and the necessity of increasing the remuneration of abstractors. In view of the considerable fall in the price of paper and a slight reduction in the charge for printing together with other possible savings, the contribution of the Institution for 1922 will be reduced.

(32) Wiring Rules.

During the Session the Editing Sub-Committee have completed the revised draft of the Rules and this draft is now being considered in detail by the Main Committee. In connection with the revision, specifications for certain electrical apparatus are being prepared by Committees of the British Engineering Standards Association. It is hoped that these specifications will be available before the new edition is finally published, so that reference may be made to them in the Rules, thus avoiding the necessity for specifying therein the details of apparatus. In view of the portion relating to Conductors and Cables being urgently required by manufacturers and others, it is proposed to issue the revised "Conductor" section in advance of the remainder of the Rules.

(33) Model Conditions for Contracts.

On the suggestion of the British Electrical and Allied Manufacturers' Association the Council have appointed a Committee to prepare Model Conditions of Contract for (*a*) "Home" orders when no erection is included in the contract, and for (*b*) "Export" orders, with or without erection.

(34) Ship Electrical Equipment Regulations.

As was stated in the last Report, these Regulations have, with certain omissions, been adopted by Lloyd's

Registry of Shipping and are now in force for all ships built under their survey throughout the world. Very few questions have arisen in connection with the Regulations.

(35) Sea-going Electricians.

A deputation of the Ship Electrical Equipment Committee has been received by the Board of Trade in connection with the steps that are being taken by the Institution, at the request of the Electrical Trades Union, to urge the Board to hold examinations and grant certificates to Sea-going Electricians.

(36) British Electrical Proving House.

Since the last Annual Report, the Wiring Rules Committee have reported to the Council as follows :—

"Very grave difficulty is found by this Committee in dealing with inquiries as to the conformity of appliances and fittings with the Wiring Rules, and the Committee is strongly of opinion that a body for dealing with questions of this kind should be set up and they recommend the Council to reconsider the question of a National Proving House."

The Council have referred the matter to a Committee for consideration and report.

(37) Proposed Scheme for the Registration of Electrical Contractors.

The Council have set up a Committee consisting of representatives of the Institution and other interested bodies, to prepare and report on a scheme for the voluntary registration or certification of Electrical Contractors.

(38) Power Lines Committee.

The Regulations Sub-Committee of the above Committee have been engaged in the revision of the Board of Trade Regulations, for (*a*) securing the safety of the Public, and (*b*) ensuring a proper and sufficient supply of Electrical Energy; also the Overhead Line Regulations for (*a*) High Pressures and (*b*) Low and Medium Pressures. Drafts of the revised Overhead Line Regulations have been completed, and that for High Pressure has been circulated amongst the Associations interested. As a result, various criticisms and suggestions have been received and the draft Regulations are consequently being reviewed. A similar course will be followed in regard to the Low and Medium Pressure Regulations, and it is hoped that a Report on both sets of Regulations will be ready before the commencement of next Session.

(39) Electricity (Supply) Bill.

When the Electricity (Supply) (No. 2) Bill was before Parliament in May 1921, the Council summoned a conference of representatives of the Electricity Supply Industry and others, and in view of the divergence of opinion among the various interests represented on the conference, decided to express no opinion on the Bill itself, but to make the following communication to the Electricity Commissioners :—

"In the event of the Bill (in regard to which the Council offer no opinion) now before Parliament being proceeded with, the Council support the principle of making the use of multi-part tariffs compulsory on application by undertakers subject to the approval of the Electricity Commissioners."

The Bill was eventually dropped by the Government. As regards the Electricity (Supply) Bill at present (April 1922) before the House of Lords, the Council will take such action as may appear to be desirable after consulting the parties interested.

(40) German Reparation Payments.

In its issue of the 17th November, 1921, *The Times* published a letter from Sir Henry Strakosch proposing that German reparation payments be made in kind, principally in the form of electrical machinery. The scheme appeared to the Council to be highly detrimental to the interests of the British Electrical Industry and the Council accordingly addressed a letter to the Prime Minister and to the Chancellor of the Exchequer taking strong exception to the proposals.

(41) Examination of Officers of Royal Corps of Signals.

For the purpose of qualifying for "Signal Pay," Officers of the Royal Corps of Signals were examined by the Institution in the "Theory of Electrical Military Signalling" at the Signal Service Training Centre, Maresfield Park Camp, Sussex, in September, 1921, and March, 1922.

(42) City and Guilds of London Institute (Grade I) Examination in Electrical Installation Work.

The Council have been glad to give their support to an application to the Board of Education from the Council of the Electrical Contractors' Association for the temporary reinstatement of the above examination which had been suspended for some years. The Board have granted the application for the year 1922 and have left the question of the future of the examination for discussion between the Board and the Association.

(43) Electrical Engineering Training in Technical Schools.

The Council received last year a letter from the Board of Education inviting the Institution to appoint a small body of representatives to discuss with representatives of the Board, at a time convenient to the Institution, the possibility of the co-operation of the Institution with the Board in the regulation of courses of study and the issue of certificates and diplomas to successful students.

The Council thereupon appointed a Committee to meet representatives of the Board, and five conferences were held. As a result a complete scheme to give effect to the objects in view was submitted to and approved by the Council. The proposals are now

under consideration by the Board of Education. The main points of the scheme are :—

(1) The abolition of single-subject examinations and the substitution of grouped courses in Electrical Engineering.

(2) A Joint Board of three members appointed by the Institution and three by the Board of Education, will be set up to manage the scheme, including the curriculum and the examinations.

(3) The entry of any school into the scheme is entirely voluntary, but no school can be included unless approved after detailed inquiry by the Institution, and such approval may be withdrawn by the Institution at any time, if found necessary.

(4) The holding of internal examinations by the approved Schools and of a final internal examination with external assessors appointed by the Institution. These assessors will review the questions set and give the final marks to the answer papers.

(5) National certificates and diplomas bearing the names of the Institution of Electrical Engineers, the Board of Education and the School will be issued to successful candidates.

The Council regard this matter as one of very great importance, tending to bring the Schools more closely into touch with the educational needs of the industry, affording a guide to young men as to lines of study, and providing for a certificate the value of which will be recognizable all over the country.

Similar arrangements have been made by the Institution of Mechanical Engineers and the Institute of Chemistry.

(44) Co-operation among Engineering Institutions.

The Council have appointed the President and Mr. R. T. Smith to represent the Institution at a conference summoned by the Institution of Civil Engineers to examine the question of co-operation among Engineering Institutions and to report thereon to the Councils of the several Institutions. The other Institutions represented, in addition to the Institution of Civil Engineers, are the Institution of Mechanical Engineers and the Institution of Naval Architects.

(45) The British Electrical Development Association.

The membership of the Association, which has been in existence for nearly 3 years, has reached a total of 610. It may be recalled that the Association was founded by the Institution and the nine principal industrial Associations representing the supply, manufacturing and contracting branches, viz. :—

The British Electrical and Allied Manufacturers' Association.
The Incorporated Municipal Electrical Association.
The Conference of Chief Officials of London Electric Supply Companies.
The Incorporated Association of Electric Power Companies.
The Provincial Electric Supply Committee of the United Kingdom.
The Cable Makers' Association.
The Electric Lamp Manufacturers' Association of Great Britain, Ltd.
The Electrical Contractors' Association.
The Electrical Wholesalers' Federation.

Members of the Institution interested in development work are recommended to communicate with the Director of the Association who will be glad to give particulars of membership and information concerning the work in hand. The Offices are at 15, Savoy-street, W.C. 2.

(46) The British Electrical and Allied Industries Research Association.

The Council of the Association now consists of 20 members, of whom seven are nominated by the Institution. The work is divided under 11 Sections and there are over 40 Research Committees. The Association has the regular assistance of about 150 experts and the occasional assistance of many others. The expenditure on research now amounts to about £16 000 per annum.

A number of reports have been issued to members and some of these are appearing in the *Journal* of the Institution. A quarterly review of progress also appears in the *Journal* and has proved useful in enabling Institution members to keep in touch with the activities of the Association.

Members are invited to communicate freely with the Director on the work of the Association, at 19, Tothill-street, Westminster, S.W. 1.

(47) The British Engineering Standards Association.

The work in connection with the Standardization of Electrical Materials and Apparatus has made further progress, and the following British Standard Specifications were issued during the year :—

B.S.S. No. 77. Electric Pressures for New Systems and Installations.
B.S.S. No. 108. Graphical Symbols for Electrical Purposes.
B.S.S. No. 109. Air-Break Knife Switches and Laminated Brush Switches for Pressures not exceeding 660 volts.
B.S.S. No. 110. Air-Break Circuit Breakers for Pressures not exceeding 660 volts.
B.S.S. No. 128. Bare Annealed Copper Wires for Electrical Machinery and Apparatus.
B.S.S. No. 133. Normal Type Vacuum Tungsten Filament Electric Lamps.
B.S.S. No. 137. Porcelain Insulators for Overhead Power Lines.

Considerable work has been done in connection with the co-ordination of the Electrical Specifications of eight Government Departments, and much of this work will become available for general use.

During the past year an innovation was made on the suggestion of Mr. C. H. Wordingham, C.B.E., one of the Institution representatives on the Main Standards Committee, whereby members of the Institution were

given an opportunity of discussing at an Institution meeting six draft Specifications for various types of Motor Starters. The result of the discussion was satisfactory and a number of useful points were brought out which are being adopted in the Specification. It is hoped that a similar procedure may be possible with other Specifications.

The B.S. Specification for Insulated Annealed Copper Conductors (B.S.S. No. 7) has been revised, and in addition a metric edition has been prepared, this latter being issued as B.S.S. No. 152.

The revision of the Standardization Rules for Electrical Machinery (B.S.S. No. 72) has been in progress for over a year, and it has been decided to sub-divide the Rules and draft them in the form of Specifications as follows :—

(*a*) Large machines.
(*b*) Transformers.
(*c*) Industrial machines.

These are in active preparation and should be available during the coming year.

Several of the Committees have been actively engaged in preparing proposals for submission to the International Electrotechnical Commission. The List of "Terms and Definitions" originally prepared by the Institution in March 1916 has been reviewed and greatly enlarged. It will not be issued until it has been considered by the Commission, and it is hoped that it will be possible to issue it in several languages.

In the List of Graphical Symbols (B.S.S. No. 108) attention is called by means of an asterisk to those Symbols which are identical with the Symbols put forward by the International Advisory Committee on Symbols for adoption by the International Electrotechnical Commission.

(48) The International Electrotechnical Commission.

The changed conditions in all countries referred to in the Report last year have made the work during the past year proceed at an apparently slower rate than formerly, each country with its own national standardizing body now finding it necessary to consult all the various interests before instructing delegates to attend the meetings.

The revision of the I.E.C. standard of resistance of copper has been completed. It will not be available for issue until it has been formally approved by a Plenary Meeting, but proof copies have been supplied to each National Committee and can be seen by those interested, on application to the Secretary of the Commission, 28 Victoria-street, S.W. 1. No alteration in the values has been made, but the method of presentation has been improved. A corresponding standard for Aluminium is in course of preparation.

A request for the co-ordination of the Rules and Regulations relating to Distribution Systems (Overhead and Underground) in the various countries has been acceded to. A questionnaire is being prepared for circulation and each National Committee will be asked to prepare replies.

The work of the Advisory Committees on Rating, Symbols, Nomenclature and Standard Pressures is proceeding steadily.

(49) Benevolent Fund.

The Committee of Management of the Benevolent Fund of the Institution report that on the 31st December, 1921, the Capital Account of the Fund stood at £7 859 7s. 3d., and the accumulated income at £1 583 16s. 9d. The donations and subscriptions to the Fund in 1921 amounted to £1 424 17s. 3d.

In the course of the year 25 grants were made to 14 persons amounting to a total of £525 5s.

The following is a comparison of the number of subscriptions and the amounts received from members up to the 15th April during the present year and for the same period a year ago :—

	Number of Subscribers and Donors	Amount £ s. d.
1922.		
1 January to 15 April ..	1 351	1 692 16 5
1921.		
1 January to 15 April ..	884	439 17 3

Reference was made in the last Annual Report to the generous offer of Mr. E. M. Hughman (late of Bombay) to present £250 to the Fund, provided 19 other donations of a similar amount were received by the 30th June, 1921. Subsequently, Mr. Hughman was good enough to extend the date to the 31st December, 1921, and entirely to waive his conditions both as to the number and the amount of the other donations. An appeal based on the offer was widely circulated and the result has been that the Fund has already benefited to the extent of £2 306 6s. 5d., as follows :

	£ s. d.
Individual contributions	1 120 10 0
Collected by Local Centres and Sub-Centres	508 11 5
Collected from members of Wireless Section by Dr. W. H. Eccles	409 18 0
Collected from Post Office Engineers by Sir William Noble	267 7 0
	£2 306 6 5

The Committee of Management are deeply grateful to Mr. Hughman, the other donors and those who made "group collections," for the valuable assistance rendered by them to the Fund.

(50) Annual Accounts.

The Annual Accounts for the year 1921 will be found on page 538 of No. 309 of the *Journal*.

Excess of Income over Expenditure.—After making provision for contingencies as in the previous year, there is a margin to the good on the Revenue Account for 1921 of £639 2s. 10d. This amount, which has been

carried to the credit of the General Fund, compares with £673 7s. 1d. in 1920, a decrease of £34 4s. 3d.

Mortgages.—

	£	s	d
In the Accounts for 1920 these stood at	29 284	15	0
Amount of repayments during the year	4 952	15	1
They now stand at	£24 331	19	11

Life Compositions Fund.—The total of the Fund on the 1st January, 1921, was £5 676 11s. Out of this the sum of £86 1s. has been transferred to the General Fund, in accordance with the Articles of Association, on account of Life Compositions of members deceased during the year, leaving to the credit of the Fund £5 590 10s.

Assets.—Taking the Tothill Street property and the investments at cost, and the Institution building and lease, the library and furniture, etc., at the values standing in the books after writing off depreciation—

	£	s.	d.
the Assets amount to	115 354	15	10
against Liabilities	6 415	7	11
leaving a surplus of	£108 939	7	11
which, in comparison with that of the year 1920, viz.	102 696	0	10
shows an improvement of	£6 243	7	1

The balance of £108 939 7s. 11d. is made up as follows :—

Assets.

	£	s	d		
Properties.					
Institution Building and Tothill Street Property	92 289	3	11		
Less Mortgages ..	24 331	19	11		
				67 957	4 0
Investments, Cash, etc.				41 102	16 10
Stock of paper, Libraries and Furniture ..				6 294	15 0
				£115 354	15 10
Less *Liabilities.*					
Trust Fund Income Accounts	442	0	3		
Sundry Creditors ..	5 654	3	4		
Repairs Suspense Account	19	4	11		
Subscriptions received in advance	299	19	5		
				6 415	7 11
				£108 939	7 11

(51) The Institution and Bodies on which it is Represented.

For convenience of reference, there is attached hereto (Appendix D) a diagram showing the organization of the Institution and its representation on other bodies.

APPENDIX A.

Membership of the Institution.

The changes in the membership since the 1st April, 1921, are shown in the following table :—

	Hon. Mem.	Mem.	Assoc. Mem.	Grad.	Stud.	Assoc.	Total.	Total.
Totals at 1 April, 1921	9	1 679	4 605	805	1 897	454		9 449
Additions during the year :—								
Elected	1	37	178	144	779	4	1 143	
Reinstated ..		5	5	3	2	1	16	
Transferred to ..		113	64	57	..	..	234	
Total	1	155	247	204	781	5	1 393	
Deductions during the year :—								
Deceased ..		17	19	1	7	10	54	
Resigned ..		12	33	9	36	17	107	
Lapsed ..		5	31	23	105	8	172	
Transferred from ..	..	..	108	42	75	9	234	
Total ..	..	34	191	75	223	44	567	
Net Increase	..	..	..	..	..	..	..	826
Totals at 1 April, 1922	10	1 800	4 661	934	2 455	415		10 275

APPENDIX B.

Meetings.

The following is a list of the meetings held during the past twelve months :—

Commemoration Meetings	5	Committees :—	
Ordinary Meetings ..	19	Benevolent Fund ..	9
Special General Meetings	5	Examinations ..	5
Wireless Sectional Meetings	7	Finance	14
Informal Meetings ..	10	General Purposes ..	11
Council Meetings ..	20	Informal Meetings ..	10
Local Centres :—		Local Centres ..	3
Irish	8	Membership	10
North-Eastern ..	13	Model General Conditions ..	4
North Midland ..	10	New By-Laws ..	11
North-Western ..	11	Power Lines (and Sub-Committees) ..	40
Scottish	7	Papers	6
South Midland ..	9	Proving House ..	2
Western	8	Registration of Electrical Contractors ..	2
Local Sub-Centres :—		Ship Electrical Equipment Standing Sub-Committee	1
Dundee	7	Technical Education ..	10
East Midland ..	11	War Memorial ..	1
Liverpool	8	Wireless Section ..	6
Sheffield	7	Wiring Rules ..	4
Tees-side	11	Other Committees and various Conferences	15
Students' Sections :—		Total ..	401
London	10		
Birmingham	9		
Liverpool	9		
Manchester	8		
Newcastle	17		
Scottish	6		
Sheffield	2		

APPENDIX C.

Addresses.

Author.	*Title.*
Lt. B. Atkinson, Past-President.	Address to the Western Centre.
W. E. Burnand, Member.	Chairman's Address (North Midland Centre).
R. A. Chattock, Member.	Chairman's Address (South Midland Centre).
R. N. Eaton, Member.	Chairman's Address (Irish Centre).
S. E. Fedden, Member.	Chairman's Address (Sheffield Sub-Centre).
E. T. Goslin, Member.	Chairman's Address (Scottish Centre).
J. S. Highfield, President.	Inaugural Address.
Prof. G. W. O. Howe, D.Sc., Member.	Chairman's Address (Wireless Section).
A. C. MacWhirter, Member.	Chairman's Address (Western Centre).
G. H. Nisbett, Member.	Chairman's Address (Liverpool Sub-Centre).
P. S. Thompson, Member.	Chairman's Address (Tees-side Sub-Centre).
Dr. W. M. Thornton, O.B.E., Member.	Chairman's Address (North-Eastern Centre).
W. Walker, Member.	Chairman's Address (North-Western Centre).
T. P. Wilmshurst, Member.	Chairman's Address (East Midland Centre).

Lectures, Etc.

Dr. J. A. Fleming, F.R.S., Member.	"Michael Faraday and the Foundations of Electrical Engineering."
Dr. C. C. Garrard, Member.	Exhibition of a Cinematograph Film, "Investigations and Tests on High-Tension Switchgear," prepared by Mr. P. Torchio.
F. Gill, Member.	Exhibition of Cinematograph Films: "The Audion"; and "Telephone Inventors of To-day."
Dr. S. P. Smith, Member.	"Single- and Three-Phase Commutator Motors with Series and Shunt Characteristics."

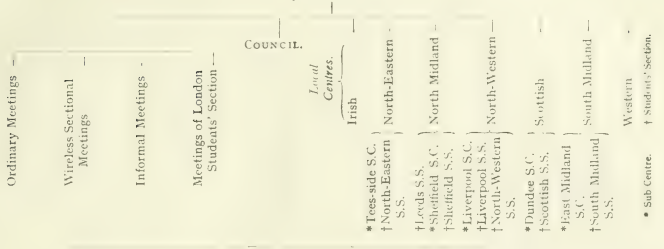
Papers Read at Meetings.

J. Anderson, Member.	"Electric Motor Starters."
R. D. Archibald, Member.	"A Method of Regulating the Voltages on the Two Sides of a Three-wire D.C. System equalized by Static Balancers."
E. S. Byng, Member.	"Telephone Line Work in the United States."
L. H. A. Carr, M.Sc. (Tech.) Member.	"Induction-type Synchronous Motors."
Lt.-Col. A. G. T. Cusins, C.M.G.	"High-Speed Wireless Telegraphy."
T. L. Eckersley, B.A., B.Sc.	"An Investigation of Transmitting Aerial Resistances."
Major J. Erskine-Murray, D.Sc., Member, and J. Robinson, Ph.D.	"Directional Transmission of Electromagnetic Waves for Navigational Purposes."
Major J. Erskine-Murray, D.Sc., Member, and B. Williams, B.Sc.	"The Determination of the Decrement of a Distant Station by means of a Coil Aerial."
C. I. Haden.	"Utilization of Exhaust Steam from Electric Generating Stations, and Coal Economy."
J. G. Hill, Associate Member.	"Phantom Telephone Circuits, and combined Telegraph and Telephone Circuits, worked at Audio Frequencies."
J. A. Kuyser, Member.	"Protective Apparatus for Turbo-Alternators."
R. B. Matthews, Member.	"Applications of Electricity to Agriculture."
E. M. Moullin, M.A., and L. B. Turner, M.A., Member.	"The Thermionic Triode as Rectifier."
L. Romero and J. B. Palmer, Associate Members.	"The Interconnection of Alternating-Current Power Stations."
L. J. Steele, Member, and H. Martin, Associate Member.	"The 'Cyc-Arc' Process of Automatic Electric Welding."
Prof. J. S. Townsend, F.R.S.	"Electric Oscillations in Straight Wires and Solenoids."
F. P. Whitaker, Member.	"Rotary Converters, with special reference to Railway Electrification."
Capt. J. H. Whittaker-Swinton, R.E., Associate Member.	"The Provision of Power for Wireless Telegraphy."
F. H. Whysall, Member.	"The Utilization of Waste Heat from Electrical Generating Stations."
W. Wilson, B.E., M.Sc., Associate Member.	"Some Notes on the Design of Liquid Rheostats."
C. H. Wordingham, C.B.E., Past-President.	"British Standard Specifications for Motor Starters."

In addition, a number of papers have been accepted for publication in the *Journal* without being read at meetings.

APPENDIX D.

THE INSTITUTION OF ELECTRICAL ENGINEERS.



COMMITTEES. (*Standing.*)

Benevolent Fund
Electrical Appointments Board
Examinations
Finance
General Purposes
Informal Meetings
Library
Local Centres
Membership
Papers
Paul Scholarship
"Science Abstracts"
Ship Electrical Equipment
Technical Co-operation
Wireless
Wiring Rules

Sectional Committees.
- Electricity in Mines
- Electro-Chemistry and Electro-Metallurgy
- Lighting and Power
- Telegraphs and Telephones
- Traction

COMMITTEES. (*Special.*)

German Reparation Payments
Model General Conditions
New Bye Laws
Patent Law
Power Lines
Proving House
Registration of Electrical Contractors
Technical Education
War Memorial

BODIES ON WHICH THE INSTITUTION IS REPRESENTED.

Birmingham Chamber of Commerce
Bradford Public Libraries Committee
Bristol University
British Electrical and Allied Industries Research Association
British Engineering Standards Association
British National Committee of the International Electrotechnical Commission
Corrosion Committee of Institute of Metals
Darlington Board of Invention and Research
Duddell Memorial Committee of Physical Society of London
Electrical Development Association
Electrical Engineering Training in Technical Schools, Joint Board
Fuel Economy Committee of British Association
Imperial College of Science and Technology, Governing Body
Imperial Mineral Resources Bureau Conference
International Scientific Unions
International Illumination Commission, British National Illumination Committee
International Testing Association
Leeds Civic Society
Leeds Municipal Technical Library Committee
Loughborough Technical College Advisory Committee
Metalliferous Mining (Cornwall) School, Governing Body
Middlesbrough Technical College
National Committee for Physics (Royal Society)
National Committee in Radio Telegraphy (Royal Society)
National Physical Laboratory, General Board
Newcastle-on-Tyne Chamber of Commerce
Paris Conference on E.H.T. Lines (Union des Syndicats de l'Electricité)
Professional Classes Aid Council
Radiographers, Society of
Röntgen Society Advisory Committee for British X-Ray Industry
Royal Engineer Board
Scientific and Industrial Research Advisory Council, Engineering Committee
Scientific Societies, Conjoint Board of
Smoke Abatement Exhibition, 1922
Technical Societies of Canada, Joint Committee
Transport, Ministry of, Advisory Panel
War Office Committee on Engineer Organization
Weights and Measures Conference, Paris
Women's Engineering Society

THE INSTITUTION OF ELECTRICAL ENGINEERS.

REVENUE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1921.

Dr. EXPENDITURE. INCOME. **Cr.**

Year ended 31 Dec., 1920. £ s. d.		£ s. d.	£ s. d.
	To Management :—		
	Salaries and Wages (including Staff Provident Scheme and War Bonus) ...	9,402 13 0	
	National Insurance	53 19 1	
	Accountants' Fees	31 10 0	
	Printing	635 14 6	
	Stationery and Office Requisites	449 16 11	
	Addressing	29 1 6	
	Postage on Correspondence and Notices	651 18 8	
	Telephone	66 8 8	
	Travelling Expenses	37 0 0	
	Bank Charges	15 14 1	
10,480 11 1			11,392 6 2
	„ Institution Building :—		
	Ground Rent	2,201 0 0	
	Rates and Taxes	2,285 2 0	
	Heating	150 1 5	
	Lighting and Power	106 0 0	
	Insurance	151 17 11	
	Reserve for Repairs	400 0 0	
	Estate Agents' Fees	15 15 0	
	Household Requisites and Cleaning ..	189 5 0	
3,581 16 3		5,505 11 1	
605 0 0	*Less* Rents from Tenants	4,800 8 0	
1,168 2 9	„ Temporary Offices (No. 1 Albemarle Street) :— Rent, Lighting, Heating, Cleaning, etc....		700 3 1 622 18 10
1,240 13 3	„ Interest on Mortgages		1,243 6 0
95 7 6	„ Furniture and Fittings (Repairs and Renewals)		100 6 7
	„ Journal :—		
	Printing	4,084 1 3	
	Postage	1,893 0 6	
	Wrappers and Envelopes	356 12 5	
		6,133 14 2	
	Less Sales	1,107 13 0	
6,539 3 3			4,026 0 5
94 11 0	„ Lending Library (Books, Printing, Postage, etc.) ...		96 18 5
5 2 0	„ Thompson Memorial Library : Insurance, etc.		5 2
—	„ Expenses in Connection with Royal Charter		368 18 8
	„ Science Abstracts :— Salaries, Abstracting, Printing, Postage, etc....	4,446 4 3	
	Less Sub-scriptions, Sales, and Advertisements	3,167 15 8	
264 7 5			678 8 7
	Carried Forward	£20,473 8 7	

Year ended 31 Dec., 1920. £ s. d.		£ s. d.	£ s. d.
22,319 16 6	By Subscriptions		28,361 1 4
1,671 13 6	„ Entrance Fees and Vellum Diploma Fees		1,826 17 0
11 17 6	„ Donations and Subscriptions towards Cost of Building		8 1 0
1,775 9 4	„ Dividends and Interest		1,985 8 4
—	„ Model General Conditions		114 0 8
22 19 9	„ Ship Wiring Rules		7 4 2
	„ Tothill Street Property :— Rents from Tenants	1,156 1 11	
	Less Ground Rent, Repairs, Alterations, Rates, Taxes, etc.	945 18 0	
557 11 0			510 3 11
	Carried Forward		£32,812 16 5

Dr. EXPENDITURE—*continued.*

		£ s. d.	£ s. d.
	Brought Forward		20,473 8 7
	To MEETINGS :—		
	Advance Proofs	153 3 0	
	Reporting	119 3 6	
	Grant to Student Section	24 0 3	
	Honorarium to Kelvin Lecturer	25 0 0	
	Refreshments, Assistance, etc.	252 0 3	
	Hire of Rooms	100 11 7	
662 17 11			674 7 1
	„ TERRITORIAL CENTRES :—		
	Money Grants	1,826 8 1	
	Travelling Expenses	544 19 4	
2,241 16 1			2,371 7 5
192 7 4	„ PREMIUMS FOR PAPERS	... ...	208 10 2
	„ SPECIAL GRANTS :—		
	Conjoint Board of Scientific Societies ...	50 0 0	
	International Electrotechnical Commission	150 0 0	
	James Watt International Memorial Fund	50 0 0	
	Books for Serbian Technical Libraries ...	49 19 7	
985 19 2			299 19 7
109 2 0	„ ANNUAL DINNER	... ...	124 16 6
492 11 5	„ CONVERSAZIONE	... ...	560 13 0
5 4 10	„ WIRING RULES (Printing, *less* Sales)	...	8 18 10
	„ EXAMINATIONS (Expenses, *less* Receipts) ...	... ...	2 7 9
54 16 0	„ RESEARCH	... ...	218 0 4
212 11 3	„ LEGAL EXPENSES	... ...	15 10 10
71 11 8	„ MISCELLANEOUS EXPENSES	... ...	67 11 8
			25,055 0 0
	„ AMOUNTS TRANSFERRED TO :—		
277 12 2	SINKING FUND (Premiums for Redemption of Cost of Building and Lease) ...	277 12 2	
3,000 0 0	RESERVE FUND (Contingencies and Mortgage Redemption)	4,000 0 0	
	GENERAL FUND :—		
	Obligatory Repayment to Economic Life Assurance Society :		
	Donations and Subscriptions towards Cost of Building £8 4 0		
	Contribution out of Revenue 944 14 1		
917 10 5		952 18 1	
	Expenditure on—		
111 18 11	Books and Binding for Library ...	111 16 0	
	Furniture	1,770 2 10	
673 3 1	**Balance carried to General Fund** ...	6,99 2 10	
			7,757 9 8
			£32,812 10 5

Cr. INCOME—*continued.*

	£ s. d.
Brought Forward	32,812 10 5
	£32,812 10 5

BALANCE SHEET, 31ST DECEMBER, 1921.

Dr. LIABILITIES. ASSETS. **Cr.**

	£ s. d.	£ s. d.
To Economic Life Assurance Society:—		
On Mortgage of Institution Building (1909) ...	20,000 0 0	
Since repaid	9,168 0 1	
	10,831 19 11	
On Mortgage of Tothill Street Buildings and Site (1916) £11,500 0 0		
Since repaid ... 4,000 0 0		
	7,500 0 0	
	24,331 19 11	
„ Life Compositions Fund:—		
Balance at 1st January, 1921	5,636 11 0	
Less Life Compositions of Deceased Members transferred to General Fund	80 1 0	
	5,556 10 0	
„ Kelvin Lecture Fund:—		
As per last Balance Sheet	648 13 0	
„ Uninvested Balances of Trust Funds	442 0 3	
„ Sundry Creditors	3,607 18 0	
„ H.M. Office of Works Suspense Account)		
Claim by Department	935 3 3	
Less Contra Account	888 18 8	
	46 4 7	
„ Subscriptions received in advance	209 19 5	
„ Repairs Suspense Account:—		
Balance (as per last Balance Sheet)	1,447 3 3	
Amount set aside in 1921	400 0 0	
Contribution from Office of Works	4,000 0 0	
	5,847 3 3	
Less Expenditure on Repairs in 1921... ...	5,827 18 4	
	19 4 11	
„ Reserve Fund (Contingencies and Mortgage Redemption):—		
Balance at 1st January, 1921	14,000 0 0	
Amount transferred to Reserve Fund in 1921 ...	4,000 0 0	
	18,000 0 0	
Less Voluntary Instalment repaid to Economic Life Assurance Society on mortgage of Tothill Street Buildings and Site	4,000 0 0	
	13,000 0 0	
Carried Forward	50,986 10 10	

	£ s. d.	£ s. d.
By Institution Building and Lease:—		
Cost	73,028 6 10	
Less Reserve for Depreciation, being Surrender Values of Sinking Fund Policies	3,656 12 8	
		69,371 14 2
„ Sinking Fund (Surrender Values of Policies for Redemption of Cost of Building and Lease)		3,656 12 8
„ Tothill Street Buildings and Site (at cost)		19,260 17 1
„ Life Compositions Investments (at cost)*:—		
£2,600 Natal Zululand Railways 3½% Debentures	2,270 12 0	
£1,500 Lancashire and Yorkshire Railway 4% Preference Stock	1,513 10 4	
£2,000 Assam Bengal Railways 3% Stock ...	1,548 0 6	
£250 Western Australia 4% Stock	243 0 5	
		5,575 12 3
„ Kelvin Lecture Fund Investment (at cost)*:—		
£694 16s. 9d. 5% War Stock		648 13 0
„ Library (exclusive of the Ronalds Library and Faraday Papers, which are held in trust):—		
As per last Balance Sheet	1,051 3 4	
Additions in 1921	111 16 9	
	1,163 0 1	
Less Depreciation (10%)	116 6 0	
		1,046 14 1
Thompson Memorial Library (Contribution towards purchase)		1,000 0 0
„ Furniture, Fittings, and Apparatus:—		
As per last Balance Sheet	1,925 0 6	
Expenditure on Furniture in 1921...	1,776 2 10	
	3,701 3 4	
Less Depreciation (5%)	185 1 2	
		3,516 2 2
„ Museum Instruments purchased from the collection of the late Sir William Crookes)		213 12 6
„ Sundry Debtors		1,711 12 6
„ Insurance Premiums and Sundry Payments in Advance ...		903 9 3
„ Stock of Paper, Etc., for Publications		518 6 3
Carried Forward		107,423 5 11

BALANCE SHEET—*continued.*

Dr. LIABILITIES—*continued.* | ASSETS—*continued.* **Cr.**

	£ s. d.	£ s. d.
Brought Forward		50,680 10 10
To General Fund :—		
Balance at 1st January, 1921	82,378 10 10	
Life Compositions of Deceased Members ...	80 1 0	
Obligatory Repayment to Economic Life Assurance Society	952 15 1	
Voluntary Instalment repaid to Economic Life Assurance Society...	4,000 0 0	
Expenditure in 1921 on—		
Books and Binding for Library	111 16 9	
Furniture	1,776 2 10	
Balance from Revenue Account for 1921 ...	639 2 10	
	89,939 15 4	
Less Depreciation (*per contra*) :—		
Library £110 0 0		
Furniture, Fittings, and Apparatus 185 1 2		
301 7 2		
H.M. Office of Works (Suspense Account) 935 3 3		
1,236 10 5		
	88,703 4 11	
	£130,686 15 9	£130,686 15 9

	£ s. d.	£ s. d.
Brought Forward		107,423 5 11
To General and Reserve Funds Investments (at cost)* :—		
£500 Western Australia 4% Stock	486 18 10	
£750 Union of South Africa 4% Stock	742 12 0	
£750 Madras and Southern Mahratta Railway 4% Debenture Stock	738 15 6	
£35 East Indian Railway "B" Annuity	791 5 4	
£1,500 South Australian 4% Stock	1,494 10 6	
£5,250 5% War Stock...	4,687 10 0	
£2,000 5% National War Bonds	2,000 0 0	
£19,375 4% Funding Loan	15,500 0 0	
£2,000 5½% Exchequer Bonds	1,991 9 0	
		28,733 1 2
„ Cash in Hands of Territorial Centres on 30 Sept., 1921 ...		533 19 10
„ Cash :—		
At Bankers'	2,797 2 8	
At Post Office Savings Bank (Uninvested Balance of David Hughes Scholarship Trust Fund) ...	1 8 3	
In hands of Secretary	197 17 11	
		2,996 8 10

JAMES DEVONSHIRE,
Honorary Treasurer.

P. F. ROWELL,
Secretary.

* The above values are subject to depreciation.

We beg to report that we have audited the Balance Sheet of The Institution of Electrical Engineers, dated 31st December, 1921, and above set forth, together with the annexed Statements of Account. We have obtained all the information and explanations we have required. In our opinion the Statements are correct, and the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of our information and the explanations given to us and as shown by the books of the Institution.

8th May, 1922.

ALLEN, ATTFIELD & CO., *Auditors,*
Chartered Accountants,
24, Martin Lane, Cannon Street, E.C. 4.

SALOMONS SCHOLARSHIP TRUST FUND.

Dr.	£ s. d.	Cr.	£ s. d.
To Amount as per last Account	2,120 19 3	By Investments (at cost) :—	
		£1,500 New South Wales 3½% Stock	1,550 5 0
		£500 Cape of Good Hope 3½% Stock	570 13 6
	£2,120 19 3		£2,126 19 3

SALOMONS SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount paid to Scholars in 1921	175 0 0	By Balance (as per last Account)	163 6 8
„ Balance carried to Balance Sheet	58 1 5	„ Dividends received in 1921	69 14 9
	£233 1 5		£233 1 5

DAVID HUGHES SCHOLARSHIP TRUST FUND.

Dr.	£ s. d.	Cr.	£ s. d.
To Amount as per last Account	2,000 0 0	By Investment (at cost) :—	
		£2,045 Staines Reservoirs 3% Guaranteed Debenture Stock	1,998 15 0
		„ Balance carried to Balance Sheet	1 5 0
	£2,000 0 0		£2,000 0 0

DAVID HUGHES SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount paid to Scholars in 1921	162 10 0	By Balance (as per last Account)	140 0 4
„ Balance carried to Balance Sheet	37 19 5	„ Dividends received in 1921	60 8 7
		„ Interest do. do.	0 0 6
	£200 9 5		£200 9 5

PAUL SCHOLARSHIP FUND.

Dr.	£ s. d.	Cr.	£ s. d.
To Amount as per last Account	500 0 0	By Investment (at cost) :—	
		£625 4% Funding Loan	500 0 0
	£500 0 0		£500 0 0

PAUL SCHOLARSHIP FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount paid to Scholar in 1921	18 15 0	By Balance as per last Account	18 15 0
„ Balance carried to Balance Sheet	25 0 0	„ Dividends received in 1921	25 0 0
	£43 15 0		£43 15 0

WILDE BENEVOLENT TRUST FUND.

Dr.	£ s. d.	Cr.	£ s. d.
To Amount as per last Account	2,580 10 2	By Investments at cost :—	
		£875 Great Eastern Railway Metropolitan 5 Guaranteed Stock	1,193 10 3
		£215 North Eastern Railway 4% Guaranteed Stock	250 10 0
		£100 London County 3½% Stock... ...	101 8 6
		£250 New South Wales 4% Stock	251 0 0
		£100 3½% War Stock	94 8 8
		£100 5% War Stock	95 0 0
		£381 15s. 1d. 4% Funding Loan...	300 0 0
	£2,580 10 2		£2,580 10 2

WILDE BENEVOLENT TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Balance carried to Balance Sheet	194 14 5	By Balance (as per last Account)	97 2 7
		„ Dividends received in 1921	96 17 1
		„ Interest do. do.	0 14 9
	£194 14 5		£194 14 5

WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. 1).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount as per last Account	1,700 0 0	By Investment (at cost) :—	
		£2,000 5% War Stock	1,700 0 0
	£1,700 0 0		£1,700 0 0

WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. 1) (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Grants made in 1921	75 0 0	By Balance (as per last Account	100 0 0
„ Balance carried to Balance Sheet	125 0 0	„ Dividends received in 1921	100 0 0
	£200 0 0		£200 0 0

ENTERTAINMENT FUND.

Dr.	£ s. d.	Cr.	£ s. d.
To Expenses of Visit to Holland	248 1 0	By Balance (as per last Account	254 3 10
„ Expenses of Return Visit to England	366 0 0	„ Contributions towards Expenses of Visit to Holland and of Return Visit to England ...	485 0 0
„ Balance in hand 31st December, 1921	108 12 0	„ Interest received in 1921	13 9 2
	£722 13 0		£722 13 0

THE BENEVOLENT FUND OF THE INSTITUTION OF ELECTRICAL ENGINEERS.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR 1921.

Dr. EXPENDITURE.	£ s. d.	INCOME. Cr.	£ s. d.
To Grants	525 5 0	By Dividends on Investments	311 12 8
„ Printing, Stationery, Bank Charges, Postage, etc.	44 10 5	„ Interest	34 7 3
„ Unexpended Balance carried to Balance Sheet	1,200 12 9	„ Annual Subscriptions	201 6 0
		„ Donations of £5 and over	134 5 0
		„ Donations under £5	280 14 9
		„ Special Appeal in connection with offer of Mr. E. M. Hughman (late of Bombay):—	
		Donations 805 8 6	
		Annual Subscriptions 3 3 0	
			808 11 6
	£1,770 17 2		£1,770 17 2

BALANCE SHEET, 31ST DECEMBER, 1921.

Dr. LIABILITIES.	£ s. d.	£ s. d.	ASSETS. Cr.	£ s. d.	£ s. d.
To Capital Account:			By Investments (Capital), at cost:—		
As per last Balance Sheet	5,709 0 6		£901 7s. 7d. Cape of Good Hope 3 % Stock	950 0 0	
Amount transferred from Income Account in 1921	2,149 17 9		£593 18s. 7d. New South Wales 3 % Stock	600 0 0	
	7,859 7 3		£420 Great Eastern Railway 4 % Preference Stock	503 18 3	
„ Income and Expenditure Account:—			£900 North Stafford-shire Railway 3 % Debenture Stock	551 0 9	
As per last Balance Sheet	2,533 1 6		£750 East Indian Railway 3½ % Debenture Stock	737 18 0	
Unexpended Balance in 1921	1,200 12 9		£300 London and North-Western Railway 4 % Guaranteed Stock	333 11 6	
	3,733 14 6		£500 New Zealand 3½ % Stock	480 18 6	
Less Amount transferred to Capital Account in 1921	2,149 17 9		£500 Canada 3½ % Stock	478 16 0	
	1,583 16 9		£1,120 6s. 3d. 5 % War Stock	1,067 0 0	
„ Sundry Creditors	44 13 10		£350 New South Wales 4 % Stock	330 18 6	
			£200 3½ % War Stock	188 17 3	
			£2,128 8s. 0d. 4 % Funding Loan	1,024 2 0	
				7,859 7 3	
			„ Sundry Debtors	2 8 0	
			„ Cash:—		
			At Bankers' £1,589 10 10		
			In hand 30 5 9		
				1,620 2 7	
	£9,487 17 10			£9,487 17 10	

I have audited the above Balance Sheet and Income and Expenditure Account with the Books and Vouchers and certify them to be correct, and have verified the Investments with Certificates from Bankers. The Investments, which are stated at cost, are subject to depreciation.

JAS. ATTFIELD, F.C.A.,
Honorary Auditor.

8th May, 1922.

DISCUSSION ON

"INDUCTION-TYPE SYNCHRONOUS MOTORS." *

North Midland Centre, at Leeds, 13 December, 1921.

Mr. H. H. Wright: The paper refers to a type of motor which I think ought to be better known and more widely used. I am sure that any piece of apparatus which gives a leading power factor will be gladly received by all power supply undertakings. In the case of a feeder which is loaded up, it means, if we can reduce the lagging current, a reduction in the capital cost of the generating plant and distributing system, and an improvement in the regulation. The result would be more economical working. In regard to the application of these motors, where an air compressor is direct-coupled to a low-speed motor, a synchronous induction motor is a great advance on a simple induction motor. The latter has a low power factor and efficiency, and small starting torque, so that the synchronous induction motor would be suitable for improving the power factor of the system. As another application I would suggest the case of a cotton or worsted spinning mill where motors of, say, 150 h.p. or over are direct-coupled to the line shaft running at a moderate speed. Such motors if run over-excited would have the effect of raising the power factor of the whole mill to approximately unity.

Mr. W. B. Woodhouse: This type of motor is of great interest to supply engineers because its development is an outcome of the requirements of large supply systems. With a large supply system it is a question of dealing not merely with idle current but with the bad effects of idle current on pressure regulation, and if by such means as these one can deal with the idle current where it is generated in the motor, not only are the transmission lines relieved of that current, but a much more satisfactory pressure can be maintained. I think that supply engineers are much indebted to the manufacturers for these developments. In any machine simplicity is a great advantage, and the introduction of an exciter and commutator and, sometimes, an exciter dealing with large currents, is not altogether pleasant to contemplate. I think it would be of assistance if the author were to indicate the amount of current that has to be dealt with in the machines to which he has referred. My experience of the synchronous induction machine has been altogether satisfactory. I find them used largely for air compressors, particularly where the compressors are kept running, and of course a very excellent field for their use is the driving of mine ventilating fans. In this case a machine is running day and night and is constantly supplying the idle current to the installation. It is not primarily to benefit the supply undertaking that idle current should be dealt with by the power user; if supply undertakings have to deal with idle current they have to charge for it. It is to the benefit of the consumer to deal with it on site. I know a number of cases where by installing motors of this type the power user has effected a substantial saving in his electricity bill by reducing his kilovolt-ampere demand.

Mr. W. E. French: I am not clear what the author means in his statement on page 167 commencing: "It is clear that if the switch is closed at a position on the torque curve," etc. I think the following is a correct interpretation of the curves in Fig. 2: Curve A represents the synchronous torque which exists due to the relative displacement between the rotating armature and main fields, when the switch to the exciter has been closed and the machine is supposed to be running synchronously. If we were dealing with a pure synchronous machine stable conditions (as a motor) would exist for a relative displacement of the armature and main fields between 0 degrees and 90 degrees (electrical) and stable conditions (as a generator) between 180 degrees and 270 degrees. In the first case the machine becomes unstable as a motor between 90 degrees and 180 degrees (electrical) and tends towards generator action and to fall out of step; while in the second case the machine becomes stable as a generator between 270 degrees and 360 degrees (electrical) which tends to further difficulties in synchronization as a motor. I shall deal only with the case of the motor, although consideration of generator action is bound to creep in accidentally. The induction-motor part is intended to run the machine as near synchronism as possible; at the same time it introduces a torque B which, although falling towards a minimum (at 180 degrees electrical), has a stabilizing effect on the synchronous motor in its unstable part (i.e. between the field displacement of 90 degrees and 180 degrees), yet it has not completely succeeded in preventing generator action. While the machine is synchronizing (i.e. when the direct-current main field has been switched on) owing to the slip any of the relative phase displacements between the rotating armature field and the rotating main field may occur; this is indicated in Fig. 2 (curves A and B) and the constant load torque D will combine to give the resultant curve C. I take it that this curve very definitely gives the torque available above the required load torque which will assist the machine to synchronize or otherwise. The latter occurs when the field switch is closed, corresponding to conditions occurring after 180 degrees (electrical). The author says ". . . corresponding to a speed lower than the mean speed" and refers to Fig. 2. There are two curve branches lower than the mean, and it is important on which of these speed curves lower than the mean, synchronizing happens to be attempted. If the switch is closed at a position on the torque curve, still corresponding to a speed below the mean, but, say, between 260 degrees and 320 degrees (electrical), the torque is not available for pulling into synchronism; as a matter of fact, in this instance a definite torque is required in addition to the

* Paper by Mr. L. H. A. Carr (see pages 165 and 342).

load torque because the synchronous motor is acting as a generator. This does not necessarily mean that the machine will fail to synchronize, but it can be imagined that a considerable current would be required in the machine acting as an induction motor to produce the required torque. One would therefore be inclined to deduce from this that the worst condition for synchronizing is when the synchronizing torque is reaching a negative maximum, while the best condition for synchronizing is just before 90 degrees (Fig. 2), and still favourable between 90 degrees and 180 degrees (electrical). This view seems confirmed by Fig. 5. Fig. 14 evidently represents the performance characteristics of a three-phase synchronous induction motor, and I understand from it that practically over the whole working range of the motor a fairly low power factor exists with a leading wattless component of the current. Presumably this machine has been built for special conditions where it is required to compensate on a system with a small power factor and lagging reactive watts. If this, however, constitutes standard practice, I think it should be abandoned, because any wattless current, whether leading or lagging, is undesirable in cables; and the leading reactive current has only then any value when balancing equivalent lagging reactive currents. It would appear to be preferable to design a machine for $\cos\phi = 1$ at about $\frac{3}{4}$ load, i.e. 200 b.h.p., because it is at this load or thereabouts that machines generally work, and only after 1·25 times full load has been exceeded to allow a lagging current component to enter without any regulation. This should be easily possible by running the saturation of the machine comparatively high and at the same time providing for a comparatively low armature reaction. This will, in addition to making $\cos\phi$ unity over a fairly wide load range, help in the actual synchronizing process, as a strong direct current in the rotor windings would probably tend to damp or minimize the negative torque which occurs roughly after 200 degrees (electrical), as shown in Fig. 2. It would also appear that the magnitude of the excitation current has a very definite bearing on the rapidity with which synchronizing does take place, and whether it takes place at all if the field is too small. Is there any provision to make the machine fool-proof in this respect, so that it can only be switched in with the correct field current for rapid synchronizing? Have any experiments been undertaken with a view to making the machine compensate for any power factor, at any desired load, automatically and completely? What are the advantages or disadvantages of synchronous induction motors with salient poles and special starter winding?

Mr. J. C. B. Ingleby: In building these machines is it very important to have a rotor with a large amount of inertia to keep the motor running whilst switching on the excitation current? In other words, must the diameter of the rotor be large? I suppose that the switching-over could be done quite easily at 2 or 3 per cent below the synchronous speed. How does the switching-over period compare with that of starting up an ordinary star-delta induction motor? What is the excitation on a 200-b.h.p. motor? In the design of this type of motor, what are the relative copper sections on the stator and the rotor? As a rule it is sufficiently difficult to get the rotor copper on an ordinary motor, but it must be more difficult with these heavy fields required for leading power factors.

Mr. S. E. Hall: I should like to ask the author whether it would not be an advantage in many cases to use a magnetic clutch and so start the synchronous motor up light; such an electric clutch can be interlocked to ensure that it does not bring the load on until the motor synchronizes, and, further, such clutches bring the load on gradually. One of the slides exhibited showed an installation with a considerable amount of switchgear. Evidently the motor was starting under load, and it seemed to me that if a clutch were used it would simplify the switching-on arrangement in many cases. Has the author considered this question?

Mr. R. M. Longman: I think that the author on page 166 has not treated the Kapp vibrator as favourably as it deserves. From some figures taken at a test on this vibrator, the power factor with a load of 200 kW was altered from 0·83 lagging without the vibrator to 0·95 leading with it. Further, the power factor of a motor at a low load is much better with the vibrator than that of a plain induction motor. The mechanical principles of rapid reversal of rotation in this type of machine are not sound. I should like to know the amount of excitation current and voltage required for a 200-h.p. motor. Apparently it will be a large current at a low pressure, in which case it is possible that trouble will be experienced due to commutation, contact resistance and possible failure of the excitation of the exciter, which is presumably self-excited. Is it possible to use a special winding for the excitation, particularly on the single-phase wound-rotor type? If such a special winding were feasible it should have more turns and require less current. Perhaps one could go a step further and use current rectified by means of an electrolytic rectifier, and dispense altogether with the commutator and exciter. A synchronous induction motor could be used with advantage for driving compressors or pumps, but, where such load is intermittent in character, arrangements should be made for continuous running by by-passing the compressor or pump, to avoid continual stopping and starting of the motor. The author has shown a lantern slide of such a motor driving a compressor and fitted with an automatic starter and stopper: this is exactly how such motors should not be used, as they have all the defects at starting of a plain induction motor. What is wanted is an induction motor which would take a leading current instead of a lagging one at starting. The question of power-factor improvement is of the greatest importance both to the supply authorities and to the consumers, particularly if the tariff is based on a kilovolt-ampere demand, as it should be. I am sure that there are numbers of cases in which if such motors were installed they would pay for their extra cost in a very short period. Another application of such motors would be for haulages where the conditions would allow of the motor being run continuously on an endless-rope arrangement or by

making use of a proper system of clutches. Such a plan would result in far fewer kicks and disturbances on the electrical system.

Mr. W. E. Burnand also took part in the discussion. The substance of his remarks will be found on page 175 in connection with the discussion at the Institution.

Mr. L. H. A. Carr *(in reply)*: I would suggest to Mr. Woodhouse that the exciting current of a synchronous induction motor can be obtained from the formulæ given in the paper, but it may be said as a rough guide that the exciting current in medium-sized machines is of the order of 200 to 400 amperes, with a voltage of from 25 to 40. Where higher currents are necessary, it is usual to arrange the secondary winding in two circuits, giving an excitation voltage of from 60 to 70 with a current of from 300 to 500 amperes.

Mr. French's alternative explanation of Fig. 2 is correct, except that the stable condition as a generator exists where the displacement or lag of the secondary is between 270° and 360°. With reference to his remarks in regard to synchronizing, at the moment the excitation is switched on the induction-motor torque equals the load torque. The best position for switching on is then surely the point 0° in Fig. 2; for, immediately the rotor lags ever so slightly, the synchronous torque rises in a motoring sense and commences to accelerate the rotor. Similarly, the worst position is at 180°, although if the rotor has an angle of lag (space) of rather less than 180° when the excitation is switched on, it will slip practically a whole cycle before it is pulled into step. Isolated machines should, of course, be built for unity power factor, but in the majority of instances a synchronous induction motor is required to balance the lagging currents taken by neighbouring induction motors. In these cases, a leading power factor and a leading component of current down to no load are advantageous.

So far as I am aware, no special precautions have been taken in practice to ensure that the exciter has generated a sufficient voltage to ensure synchronization, before allowing the throw-over switch to be operated. Since, however, it is the practice to leave the exciter rheostat in the normal working position after shutting down, there appears to be no particular need for a fool-proof device of this sort, though it could be fitted if desired.

So far as I am aware, no automatic field control to determine the amount of leading current supplied has yet been adopted, though the matter has been considered in certain cases. It has been proposed, for instance, in the case of a machine working at the end of a long line, in parallel with other loads of a lagging character, to increase the excitation and hence the power factor of the system by means of an automatic voltage regulator, when the voltage at the end of the line falls. Except for a single "freak" machine, I am not aware that any synchronous induction motors have been built with salient poles, nor do I think it likely, as this would very much impair their induction motor characteristics.

In reply to Mr. Ingleby, it is not important to have a large amount of inertia in the rotor; rather the reverse, in fact. Oscillograms show that the stator circuit is interrupted during the switching-over period for only about 0·04 to 0·05 second, and the stored energy of the machine is quite capable of carrying the load for that time without any appreciable drop in speed. Further, since the chief problem in the synchronous induction motor is to accelerate the rotor from induction to synchronous speed in a limited time, it follows that an increase in inertia has a harmful rather than a beneficial effect. This is, of course, true with any self-synchronizing machine. The excitation of a 200-h.p. motor, from the figures given in the paper, would be about 32 volts and 150 amperes if the starting voltage were 1 500 and the pull-out torque 1·75 times full-load torque. The cross-section of rotor copper is usually somewhere about twice the cross-section of stator copper, though this figure varies considerably with different designs.

The hand-operated clutches referred to by Mr. Hall are sometimes used with salient-pole synchronous motors, and where they are installed and working satisfactorily there is no necessity for the use of a synchronous induction motor. Such clutches are, however, not often used for large powers, on account of the large amount of heat which they have to dissipate. The switchgear of a synchronous induction motor cannot be considered excessive, as the only switchgear beyond that needed for a plain induction motor is the exciter throw-over switch.

In reply to Mr. Longman, the exciter for a synchronous induction motor is always self-excited, but I have never heard of a case where such an exciter has lost its excitation or failed to excite. I cannot agree with Mr. Longman's sweeping criticism that contactor switchgear should not be applied to synchronous induction motors. Each case must be judged on its merits, and in some cases there is a great deal to be said for the adoption of such switchgear.

North-Eastern Centre, at Newcastle, 9 January, 1922.

Mr. T. Carter: It is clear that the really important point about the induction-type synchronous motor is that it can be used for power-factor correction. The subject of power-factor correction is one that is necessarily occupying the attention of all supply authorities at present, and it is my view that if anyone installs a motor of this type he ought very carefully to ascertain whether he is not paying the additional price of the machine merely to benefit the supply authority without reaping any corresponding advantage himself. Unless the user of such a motor has an installation in which the cost of cables is a very large item, or unless he has his own generating station and wishes to use his plant to the best possible advantage, the power factor at which his system works usually need not particularly concern him; it is, however, greatly to the advantage of a supply authority that power-factor-correcting apparatus should be installed on its system, and, since

the benefits are mainly for the supply authority, the latter might reasonably be expected to be willing to pay for the benefits it receives. It is, in my view, scarcely fair to penalize a customer on account of power factor, unless his power factor is materially worse than the average for his particular type of installation, and except under such circumstances I do not think that a supply authority can ever reasonably demand the installation by any of its customers of power-factor-correcting apparatus. If, therefore, any consumer whose working conditions are normal installs a motor of the type described by the author, he really has a valid claim on the supply authority for compensation, and otherwise it is difficult to understand what inducement there is for anyone to install such a machine under any circumstances. The author compares the induction-type synchronous motor with other synchronous motors and with corrected induction motors, but I should like to have a comparison between the author's type and a plain induction motor without any accessories, because such a motor is the type in common use at present and has proved itself highly satisfactory to users. It occurs to one on comparing such a plain induction motor with one of the author's type that the starting characteristics are the same; that the plain induction motor has a higher overload capacity; that it is probably rather more reliable because the induction-type synchronous motor has auxiliary machinery connected with it; that it is not possible to lift the brushes and short-circuit the slip-rings of the induction-type synchronous motor, while it is frequently possible to do so in the case of the plain induction motor, which would therefore tend to have rather lower maintenance costs; that many plain induction motors may be installed quite suitably with squirrel-cage rotors, an advantage that is impossible with the author's type; and that the plain induction motor appears to have the better efficiency and is certainly the cheaper of the two. The only obvious advantage that the induction-type synchronous motor possesses is that it can be used for power-factor correction, and even this advantage, as has been suggested, is more in favour of the supply authority than of the private individual who may purchase such a machine. It does not necessarily follow that constant speed is an advantage, and there are many cases where it is the very opposite. It would be interesting to have a comparison of the price of an induction-type synchronous motor with that of a plain induction motor working at the same power factor at full load in conjunction with a phase advancer, e.g. a vibrator. I suggest that, after all, the author's motor is very little different, so far as the user is concerned, from a corrected plain induction motor. The exciter is comparable with the phase advancer because it injects magnetizing current into the rotor, and although incidentally the methods of operation are slightly different in the two types because of the difference between their speed characteristics, they are, in my view, practically comparable. It is true that a greater amount of power-factor correction can be economically obtained from an induction-type synchronous motor than from the other, but the question of whose is the advantage is again immediately raised by that particular comparison; there may be cases where correction up to a leading power factor of 0·9 is more than is required, and my reading of the paper leads me to think that unless the full amount of power-factor correction up to 0·9 is used the induction-type synchronous motor may suffer seriously in its overload capacity. The comparison that I have attempted to make shows that it is very important to consider carefully which type of motor is better for any particular case, and I think it indicates that, while there is no doubt a wide field of usefulness for the author's type of motor, there are many instances in which its installation would not necessarily be worth the additional cost that would be incurred; and there are some in which its use would be a positive disadvantage.

Mr. F. H. Downie: When discussing the advantages of the synchronous induction motor, the author states that the commutator of the exciter commutates direct current. This is not quite correct, since the exciter generates alternating current and the commutator commutates this to direct current (alternating current of zero frequency), whilst in the phase advancer the commutator commutates alternating current from the frequency induced in the rotating winding to the frequency of slip. In all a.c. commutator motors running at constant speed the commutation can be made quite as perfect (while running) as in direct-current machines of the same voltage and current. I do not consider that the commutator of a phase advancer need give any more trouble than the commutator of the corresponding low-voltage direct-current exciter. The author states that the core loss is frequently reduced when running as a synchronous motor. This is probably due to the fact that in an induction motor the M.M.F. wave is not a sine wave but has higher harmonics. These higher-harmonic M.M.F. waves move at speeds inversely proportional to their order relatively to the rotor and induce eddy currents in the rotor iron and rotor windings, which increase the loss in the rotor. When the flux is produced by the rotor, the rotor losses vanish and so the core loss apparently diminishes. The presence of these harmonic currents can be seen in an oscillogram of the rotor current. The rotor current wave-form is continually changing. I should expect to find a similar effect in the case of two-phase and single-phase rotors. I should be glad if the author could give in his reply the value of the ratio (stator M.M.F.)/(rotor M.M.F.) when the motor is running at full load with a leading power factor of 0·9 and with an overload capacity of 100 per cent. These motors are of great utility in the case where the users generate their own power. They will in many cases enable additions to be made to the motors used in the plant without adding to the generating capacity of the station, as a result of the improvement of the power factor at the generators.

Mr. A. B. MacLean: There is no doubt that a demand exists at the present time for synchronous motors and is likely to increase in the future. The disadvantage of the standard type of synchronous motor is that only a comparatively small starting torque can be obtained, and the machine described in this paper fills a want for a machine which can be run at a high or leading

power factor and which at the same time can give a very good starting torque. There are a number of instances where synchronous machines are useful, of which the following are the most important. First there is the case of the electric installation where the power requirements are met by the use of a small isolated plant. The advantage of using synchronous machines for one or more drives is in the increased generator capacity rendered available by power-factor improvement. Then there is the case of a motor which has to be installed at the end of a long feeder where cable costs and cable losses may be reduced by the installation of a synchronous machine. The third case is the consumer of electric power who takes his current from a public supply and is charged on a basis depending on the power factor of his installation. In considering the use of the synchronous induction motor, however, it would be well to compare its characteristics with those of the salient-pole machine. The latter has certain advantages, among which are: (1) In general the salient-pole machine is cheaper in first cost; (2) the efficiency may be from 1 to 2 per cent better; (3) it is easier to obtain a high overload capacity, and (4) the amount of power-factor correction which can be obtained from the salient-pole machine does not fall off to the same extent when the machine is overloaded. It appears to me that the only advantage of the synchronous induction motor lies in its starting characteristics, but there is no doubt a field for this type of machine in cases where power-factor improvement is required, and the torque required during the starting period is comparable with the normal torque of the machine. The author mentions three possible applications of these motors, viz. for driving compressors, centrifugal pumps, and colliery fans. Compressors and centrifugal pumps can readily be unloaded when starting, and under these conditions can be started up by means of synchronous motors of the salient-pole type, fitted with damping windings. In the case of colliery fans, it will generally be more convenient to run up to speed under load conditions, the torque being practically equal to full-load torque at the point of synchronizing. Under such conditions the synchronous induction motor described in the paper would appear to meet all requirements.

Mr. J. Rosen: The author describes the motor as "the induction-type synchronous motor," but in practice it appears to be more of "a synchronous-type induction motor," that is, an induction motor with certain synchronous characteristics. I should prefer to see in the design more of the details peculiar to the synchronous type of motor, and to have either a salient pole, or barrel formation of rotor. It will be appreciated that the motor acts as an induction motor at the starting period only, and it runs synchronously when in normal operation. There is undoubtedly a wide field for the motor, but I can see no reason why the price should not be reduced so as to be more in line with that of an induction motor. I cannot understand why, under the heading "Theory," the author states that there are two ways of running the motor, either by utilizing the excitation to obtain the leading power factor of 0·9, or by increasing the air-gap of the machine and using the excitation to drive the flux through the increased air-gap. Why not re-design the motor entirely, with a smaller body, and obtain the advantage of reduced cost, with perhaps not such good leading power factor? What are the approximate exciting voltages for the various sizes of machines, and what percentage of the power is required for excitation? The voltages used appear to be comparatively low, and this means increased cost in the exciter. Presumably the power factor of 0·9 referred to on page 172 is a leading one, as it is reasonable to expect the ordinary large induction motor to run with a lagging power factor higher than 0·9 at full load.

Mr. A. T. Robertson: One feature of the synchronous induction motor, claimed on page 166 as an advantage over induction motors fitted with phase advancers, etc., may under certain circumstances appear as a disadvantage. Correction to a leading power factor is not always desired—for example, one motor working at the end of a long transmission line—but with a synchronous induction motor in order to obtain the necessary overload capacity the size of the machine must be such that it could give a leading power factor of 0·85 or 0·9. Other things being equal, it would seem that phase advancers or vibrators have the advantage for this particular condition. The only mention of two-phase rotors in the paper is for a rotor where one phase is short-circuited to act as a damper winding after the motor is up to its full induction-motor speed; it would be interesting to know if a proper two-phase winding has been tried, and, if not, what is the objection to it, because one would imagine that when used as a direct-current exciting winding the copper would be used to better purpose than with a three-phase winding where two of the phases carry only half the exciting current. I assume that in calculating the slip of a motor from which it is to be synchronized the resistance of the exciter armature and brushes is included. This extra resistance will be small compared with the rotor resistance, say about 10 per cent, but it is conceivable if working close to the limiting slip that its exclusion from the calculations would mean the difference between the motor synchronizing and not synchronizing. On page 167 it is stated that since the speed is not constant the angle swept out is not proportional to time, and the areas of the torque curves in Fig. 2 are not proportional to the work done; this statement is not at all convincing as it stands, because one would imagine that a torque multiplied by an angle was proportional to work done, irrespective of time or speed. A fuller explanation of this point, and also of the construction of Fig. 10, would add materially to an understanding of the paper. As the author points out, the single-phase rotor has the disadvantage of a marked drop in torque at one-half synchronous speed. Unless precautions are taken with the design of a motor fitted with such a rotor, the torque against which the motor will get up to speed may be limited by this factor rather than by the synchronizing torque. If a standard liquid starter with earthed dippers is used for the arrangement shown in Fig. 15 (*b*), the low-voltage exciter will be flashed with something like 30 times its normal voltage every time the motor is started; it would therefore seem to

be worth while with this arrangement to use an insulated starter and to earth the exciter. From the author's remarks one would wonder why "inverted" machines were not always used for low- and medium-tension motors; is the reason for this that the stator core can be more easily cooled than the rotor core, and that the large majority of the iron losses always occur in the primary? The reason for the suggestion that the core losses are greater for motors with single-phase and two-phase rotors than with three-phase rotors would be of interest.

Mr. J. M. Heslop: Mr. MacLean has raised an important point in asking whether this machine is superior to the salient-pole motor. It seems to me that each machine may have a sphere of utility and that the line of demarcation between them will be the starting characteristics of the load to be driven. Some of the more general applications of synchronous motors are for compressors, pumps and colliery fans. A well-designed air compressor should get under way and run up to speed with about 30 per cent of full-load torque, provided—as is now almost universal practice—an unloading valve be fitted. A centrifugal pump should run up to speed with considerably less than full-load torque, but a colliery fan is a different proposition. A fan load builds up very rapidly as the fan runs up to speed—approximately as the cube of the speed—and it is not usually feasible to arrange any device similar to a compressor unloading valve. Of these three classes of load, I think the last named, i.e. the colliery fan, is a very promising field for such a motor as described in the paper, but in the case of compressors and centrifugal pumps I am not sure that the machine possesses any advantages over the salient-pole type of motor. It would be useful if the author, in his reply, could indicate what he considers to be the superior features of the induction-type synchronous machine in these cases. The general question of power-factor correction has been raised by Mr. Carter, who expressed the opinion that this machine would benefit only the supply authorities and drew the inference that the consumer would be incurring additional expenditure on which he would get no return. The man who uses a 50-h.p. machine where a 20-h.p. machine would do, simply because he has the larger machine already and wants to standardize that size, is taking wattless current to suit his own convenience. The man who persists in using low-speed direct-coupled motors because he is afraid of gearing, is also taking wattless current to suit his own convenience. It is not improbable that before long these consumers will have to pay for this privilege of suiting their own convenience at the expense of the supply authority. At present they are getting something for nothing, a state of affairs which cannot be permitted to continue. A time is coming when the consumer will have to choose between paying for wattless kVA or, alternatively, for power-factor correction. The induction-type synchronous motor, therefore, contrary to Mr. Carter's opinion, is a machine which is of considerable interest to the consumer.

Mr. W. T. Maccall: As curve E in Fig. 2 crosses the "mean speed" line at 90°, should it not re-cross at 270°? Does the author's statement that "The mean speed is seen to occur when the synchronous torque is a maximum" apply to all cases or only to special ones? I should expect that the mean speed would occur when the resultant torque (curve C in Fig. 2) is a maximum, rather than when the synchronous torque (curve A) is a maximum, as stated by the author. If this suggestion is correct it does not invalidate the succeeding work, for the synchronizing effect will be rather greater than that calculated on the author's assumption. The tests given on page 170 tend to support this view as in three out of four the observed limiting slip was higher than the calculated value. The paper does not make clear whether the "mean speed" shown in Figs. 2 and 3 is a "time-mean" or a "space-mean," but from Fig. 3 it appears not to be the former, as the area above the mean is greater than that below it. The true "space-mean" of this curve will be higher still; so possibly the "mean speed" is averaged over the values of α. If this last supposition is correct does it remain true, as stated on page 168, that the "mean speed" is equal to the original induction-motor speed?

Mr. L. H. A. Carr (*in reply*): I quite agree with Mr. Downie that my description of a d.c. commutator is rather loosely worded. When the machine is working as a generator, the commutator commutates to direct current. I cannot agree, however, that in practice the commutator of an a.c. machine gives as satisfactory operation as the commutator of a d.c. machine. I do not think that Mr. Downie's explanation of the difference between the core losses of a machine when run synchronously and when run asynchronously, is correct. When running light as an induction motor the periodicity in the rotor is much less than 1 per second, so that any iron loss due to this periodicity—whether due to the fundamental or to space harmonics—will be negligible. The value of the ratio (stator M.M.F.)/(rotor M.M.F.) when a synchronous induction motor is running at full load with a leading power factor of 0·9 and an overload capacity of 100 per cent will be 0·555, that is to say 0·5/0·9.

Mr. MacLean raises the question of relative cost of synchronous induction motors and salient-pole synchronous motors. In general, when all accessories are included there is practically no difference in cost. Sometimes one is a little cheaper, sometimes the other, while in the very small sizes, e.g. 50 to 100 kVA, the synchronous induction motor usually has the advantage.

With reference to Mr. Rosen's remarks under "Theory," I think he has overlooked the fact that the excitation has to be kept up to a certain value (in ampere-turns) in order to provide the overload capacity, and the vectorial difference between this value and the component necessary to balance the armature reaction has to be utilized either in magnetizing the machine (large air-gap) or in supplying a leading component of current to the line (small air-gap). Exciting voltages usually vary from about 25 to 40 with small machines, and 50 to 60 for large machines with series-parallel secondary windings. The excitation loss varies from about 5 per cent in small machines to about $2\frac{1}{2}$ per cent in large machines.

In reply to Mr. Robertson, two-phase 3-wire rotors are in use but, contrary to his expectations, the copper

is not used so efficiently as in the three-phase rotor. Other things being equal, the loss in a rotor where the whole winding carries the same current is 12 per cent more for the same fundamental sine wave of flux than in the case of the three-phase winding with currents in the ratio $1 : \frac{1}{2} : \frac{1}{2}$. On this point I would refer him to the discussion at the Institution. The exciter armature resistance would have to be taken into account when calculating the limiting slip for synchronizing, but the figure of 10 per cent assumed by Mr. Robertson is much too high ; 3 or 4 per cent is more nearly correct. Further, one would always allow considerably more margin in synchronizing power than a mere 3 or 4 per cent, so as to cover variations in supply pressure, load, etc.

Mr. Robertson's difficulty in regard to Fig. 2 may be cleared up if it is explained that the abscissæ do not represent the total angle swept out. They represent only the lag of the rotor behind the synchronous field. As the speed at which the lag increases is not uniform, the increase of lag is not proportional to the total angle swept out, and is therefore not proportional to the work done. A fuller description of Fig. 10 is given in my reply on page 179.

For mechanical reasons, it is necessary that the rotor of an inverted machine should have an even number of conductors per slot, preferably 2 or 4, so as to build into a barrel winding. Where this can be arranged it is usual, with some manufacturers at any rate, to make the machine "inverted." Where this cannot be arranged, the ordinary construction of primary winding on the stator is reverted to.

Mr. Robertson reads rather more into my remarks in regard to core losses than I intended to infer. The reduced core loss when in synchronism has been proved, to my knowledge, only in the case of three-phase rotors. Whether it is the case with other types of windings has not yet, so far as I am aware, been proved. It is still an open question. My own impression is that with a single-phase winding covering two-thirds of the pole-pitch the reduction in core loss would still take place, but with a true two-phase winding, or any winding uniformly distributed and excited, the difference would probably disappear.

In reply to Mr. Heslop, I quite agree that there is, in the majority of cases, no reason why a salient-pole motor should not be used for compressors and centrifugal pumps. For fans and ram pumps, however, the synchronous induction motor is immeasurably superior.

In reply to Mr. Maccall, from inspection of various diagrams drawn for different cases it appears that the coincidence of mean speed with maximum synchronous torque is almost exact. So far it has not been proved for all cases, and I am not certain how far it is a mathematical truth. The mean speed cannot occur when the total torque is a maximum. This has been shown by Rosenberg,* and is also referred to in my reply to the discussion at Birmingham (see page 193).

The mean speed referred to in the paper is the time-mean. The torques present may be considered to be made up of a constant induction-motor torque equal to the load torque D in Fig. 2, an oscillating induction-motor torque above and below this mean, and an oscillating synchronous torque. The sum of these oscillating torques is the difference between curves C and D in the same figure (shown cross-hatched). The speed curve E is symmetrical round the zero point of this oscillating-torque curve, and therefore the net amount of work put into the rotor by this oscillating torque is zero. Consequently, the load has to be carried entirely by the so-called constant part of the induction torque, and the mean slip, and hence the mean speed, must remain the same as before the excitation was switched on, neglecting any slight difference due to the resistance of the exciter armature. Since the speed curve E is symmetrical about the point where curves C and D cross, it follows that the mean speed will be passed through not when the angle of lag is 270° (see Fig. 2), but before the lag has reached that value.

* *Journal I.E.E.*, 1913, vol. 51, p. 62.

DISCUSSION ON

"THE UTILIZATION OF WASTE HEAT FROM ELECTRICAL GENERATING STATIONS." *

North-Western Centre, at Manchester, 21 February, 1922.

Mr. S. L. Pearce: The combination of heating and electrical loads is certainly an attractive proposition, and on theoretical grounds few would find it easy to frame a case against such a scheme. Unfortunately, only those who have tried or are interested in such a scheme fully realize the many practical difficulties. In short this proposal, I think, is another illustration of the fact that the theoretically perfect scheme is not always, or seldom, commercially attainable. We in Manchester have been interested in the subject for quite a period, and during my visit to the United States in 1919 I had an opportunity of investigating one of the largest heating systems, namely, that belonging to the Detroit Edison Company, and of conferring with Mr. Walker, the Engineer-in-Charge of the plant, to whom I am indebted for much information. Some of the figures given by Mr. Haden, particularly those on page 266 and the first part of page 267, ought not to go unchallenged. The comparisons drawn between the efficiency of gas stations and that of electrical stations (very much to the detriment of the latter) I believe to be entirely erroneous. Mr. Haden quotes a very great authority on all gas questions, namely Sir Dugald Clerk, and one rather hesitates to challenge anything that he may say, but I notice that it is stated, on the authority of Sir Dugald, that gas converted into heat may reach an average efficiency of 42 per cent. I believe that in the recent "James Forrest" lecture by Sir Dugald Clerk the figure of 46 per cent appears. I suggest that a fairer figure would be 37 per cent. We have to contrast that with the figures given for the efficiency of conversion of coal into electrical energy in generating stations. Mr. Haden has to a very great extent met some of my criticisms by producing figures on the authority of the Electricity Commissioners. I will give one or two further figures from that Report. The thermal efficiency of electrical stations in the areas into which the Commissioners have delimited the country varies from 7·56 to 17·75 per cent. In that connection Mr. Haden gives an average figure of 14·56 per cent. With regard to the new stations, however, the figure he suggests is hopelessly low. There is every reason to suppose that 20 per cent will be obtained in the future, and one station is expecting to get something like 25 per cent, which approaches the figure mentioned by Mr. Haden. What we need is a true comparison between the heat units in the coal which are utilized in the production of gas and electricity respectively, and that brings in two other factors, viz. the efficiency of transmission and the efficiency of application. On the assumption that gas contains 25 per cent of the heat of the coal, I do not think there is any difficulty whatever in showing that to give the consumer the same amount of heat requires the destruction of less coal at a modern electrical station than at a modern gas-works. There are other figures in the paper which I think are open to objection. Take the question of the loss from cooling towers. I think that in that case the figure of 1 per cent of the total volume of water circulated is one that most electrical engineers will accept to-day, and therefore Mr. Haden's figures are about twice as high as they should be in that connection. Then, again, the figure of 17 lb. of steam per kilowatt-hour for a 15 000-kW set is open to criticism, as being on the high side. Coming now to the main point of the paper, and accepting the general statement that the heat carried away by the condensing water in the central station is equivalent to about 50 per cent of the coal burned, the problem is how is it possible to utilize commercially that waste heat. In the discussion in London a great deal of controversy seems to have taken place on that point. One speaker went so far as to suggest that it was really necessary to scrap waste heat units in order to get what he termed "high-grade energy." The first difficulty, as Mr. Haden points out, is to get a market. If that is assured, the method by which the heat can be obtained and transmitted from the power station must be considered. In general I think there are three methods. First of all, steam may be drawn off through a condensing turbine or condensing engine after partial expansion. In that case the primary object of the station is electricity supply, and heat distribution is secondary. The second method is to put down separate boiler plants, primarily for heating purposes, to deal with the heating load in the vicinity of the station, and at the same time to install a sufficient number of non-condensing generating sets to provide the requisite amount of pure exhaust steam to supply the requirements of the heating load. In that case the balance of the electrical load on the station, assuming it is an old one, will have to be met from one or more of the modern stations, which of course will be arranged to operate condensing. In that case the heating supply is the primary object of the station and the electricity becomes a by-product. The third method is obviously the direct supply of live steam. I submit, as the result of my experience, that no single one of these three methods is likely to satisfy all conditions or all localities. If the main generating station happens to be in the centre of the heating load, the first method, viz. to tap or bleed the generating set, is probably the only one that can be used commercially. But how often is that the position? In the case of new stations, at any rate, the questions of land, fuel and water determine the location, and generally the site is at such a distance from the heating load as to preclude

* Papers by Messrs. C. Ingham Haden and F. H. Whysall (see pages 265 and 271).

all possibility of transmitting steam on an economical and commercial basis. The second method applies more particularly to older generating stations. Current is generated to the extent of the exhaust steam required for heating, and the balance of the electrical load is made up from other stations. That, to my mind, is very attractive, especially in the case of the older electricity undertakings which possess both old and modern stations. The former will undoubtedly pass out of use with the advent of the latter. In many cases their capital costs are almost entirely written down; therefore, if it is possible to continue to use a limited number of those older sets in the older stations, under not too unfavourable conditions, it seems to me that such a scheme offers by far the best chance of successfully developing this joint supply of heating and electricity. If, however, the conditions for operating these older plants in the older stations are too unfavourable, the method of supplying live steam must be used. That seems to be the position that a large number of the American undertakings are taking up, based upon their fairly lengthy experience. The difficulty of finding a market is small compared with that of trying to co-ordinate two loads, viz. heating and lighting and power. Figs. 1 and 2 certainly bring out this point. It will be noticed from these figures that (to use an electrical term) the heating load "leads" the electrical load. This lack of agreement or coincidence varies from day to day and from week to week; and nothing will materially alter that situation, for the simple reason that the heating load is largely determined by, and depends upon, climatic conditions. Various proposals or suggestions have been made for levelling-up or balancing the two loads, e.g. thermal storage. In the case of Manchester the only way in which we can get over the difficulty is by the liberal use of live steam at times. It is estimated that of the total steam which we supply for the purpose of heating the buildings mentioned by Mr. Haden some 25 per cent is live steam. A few weeks ago my attention was called to an article in the commercial issue of the *Manchester Guardian*, which stated that the Barton station appeared to have been built with the idea that no central heating would ever be used, and that the condensing turbine would run for ever. One sometimes wonders, when reading such articles, whether the authors have ever estimated the total amount of heat that is likely to be required in connection with central heating loads in comparison with the exhaust steam available from the plants, rapidly increasing in size and aggregate capacity, which are being put down. Here again I may quote from Detroit. In that city the exhaust steam available from the electrical plants at their several generating stations is more than five times the quantity that can be commercially supplied for central heating. The main point to emphasize is, I think, that the electrical load will always greatly exceed the heating load. I submit that Figs. 1 and 2 present the case for steam heating in too favourable a light. According to these we may expect in the winter a heating load factor of about 50 per cent and in the summer about 42 per cent, or an output ratio between the two of 5 to 1. Our experience is that in the winter the heating load factor is 13·5 per cent and in the summer 40, and the output ratio is no less than 15 to 1. Emphasis should certainly be laid on the commercial aspect of this problem. By that I refer to the question of distribution. Unless basement wayleaves can be negotiated, the cost of pipe lines, subways and ducts, even if room can be found for them in our congested thoroughfares, will certainly be a very expensive item. Some figures of cost may be stated. In connection with a tunnel about 10 feet square that we drove under Whitworth-street to give a steam supply to the Refuge Assurance Co., the cost was about £6 per yard. That was a pre-war figure. Before that time a cable subway about 50 square feet for the Stuart-street station cost £27 per yard. I am indebted to the City Engineer for some figures representing present-day cost. For a steam main subway with a cross-section of about 10 to 12 square feet the estimate of present-day cost for Manchester is £30 per yard. For a main subway 30 or 40 feet down, for all the public services, the cost might be as much as £100 per yard. For this reason it may be very difficult to get a commercial market for the steam. Coming now to the question of the price at which supplies of this character can be given, I think Mr. Haden is too optimistic in thinking that we shall experience no difficulty to-day in getting prices such as 4s. per 1 000 lb. I do not doubt that the supply is worth this figure, but unfortunately it cannot be obtained. On the other hand I think Mr. Whysall's figures, on the present-day conditions, are on the low side. The rate, of course, should have a variable clause for coal, but I would suggest it should also take account of the varying load factor; so that we may have, as in electricity, not only a unit charge but also a demand component. Therefore, especially as one is really unable to forecast exactly how the steam will be supplied, and to what extent it will coincide with the electrical load, it appears to me that, in order to be really on the safe side in framing estimates, one must proceed upon the assumption that the bulk of the supply will be live steam. In Detroit they began as we began in Manchester, but they have changed their method of operation and they now distribute nothing but live steam. The conditions in Detroit do not necessarily apply to this country and therefore I am wary of coming to conclusions founded upon American practice, but it is useful to know something of the experiences in that country, more especially when electrical engineers in this country are being taken to task for throwing away waste heat and failing to recognize that the doom of the big condensing turbine has already sounded. There are four heating stations located in different parts of Detroit city. Steam is generated at 130 lb. pressure. The area of supply is about 1 mile square, and the distributing mains, which vary in size from 4 inches to 20 inches in diameter, are arranged more or less upon the approved chessboard plan, and are laid about 5 ft. below the level of the roadway. The feeders are some 6 to 12 inches in diameter. The feeder is so designed as to give a pressure of about 30 to 40 lb. at the point where the feeder joins the distributor. The

boiler pressure is 130 lb., but that is reduced to something like 85 to 90 lb. The control through the reducing valve is automatically and electrically obtained. Mr. Haden refers to the necessity of exhausting at a back pressure of 60 lb. Of course the transmission capacity of any heat-transmission system is greatly increased by raising the pressure, as live-steam conditions are more closely approximated to. The pressure quoted is very much higher than any we have been using in Manchester. To sum up, there is a great deal of useful heating load that can be obtained by a judicious combination of the three methods to which I have referred, but no single one, I think, will be entirely applicable to existing conditions, at any rate so long as the great disparity obtains between the heating and the electrical demands. The obtaining of a heating load upon a commercial basis will, of course, be much facilitated by keeping down the distribution costs; especially is it facilitated if the capital cost of the station plant to be used is largely written down.

Mr. J. Frith: There seems to be no doubt that this question requires consideration. It is not right to go on wasting heat at the power stations when there is such an urgent demand for it elsewhere. The demand may be from works using process steam, from big blocks of offices and public buildings or from domestic houses. I believe that Mr. Whysall is right in saying that it is mainly a matter of getting the parties together to arrive at a workable commercial arrangement. So long as this question is left in the hands of power station engineers who are interested in and responsible for the power station as a power station only, nothing will be done. Their whole professional ambition is to turn out a unit of electricity for a fraction less than anybody else. We must have a man whose main object is to see that none of these watertight compartments which constitute the machinery of our social life wastes what another department wants. When the supply is municipal a liaison officer is required to fill this function of co-ordination in our communal life, but it is doubtful whether the official mind can really grasp the situation. What is wanted is the intelligent and enthusiastic amateur on the city council. I have shown elsewhere that the waste heat from a station supplying both the industrial and domestic electrical needs of a community is of the right order of magnitude to supply its heat needs also. There may be a difference in the load curves of the two demands, which difficulty, however, may be made too much of, considering the enormous thermal storage in the hot water circulating in the system. It is advisable to keep in mind that it is the latent heat of the steam which one really wants to use, which points to the necessity of condensing the steam used in the power engines at a low vacuum and using the heat in the circulating water. The station condenser then becomes a calorifier with the distributing mains replacing the cooling towers. The vacuum on the steam side of the calorifier is under the control of the station and can be varied to suit the requirements at different parts of the day and year. This does not involve such a large number of pounds of steam per unit and therefore such a large capital cost per kilowatt, as attempting to take out steam from the prime movers at a pressure substantially above atmosphere. In this connection I agree with Mr. Pearce's suggestion that the city station should be run to conform to the heat demands, the difference between its electrical output and the demand to be made up, or taken up, by the mains from the super-power stations. The only factor that makes the super-power station idea tenable is that its mains can absorb power where power is surplus and distribute it out where power is wanted. The difficulty of finding ways for the mains in congested areas is very real. Let us at least make a beginning in the new industrial and residential districts. I have shown in the same place that neither the cost of the pipes nor the heat lost from them is incompatible with a satisfactorily cheap supply of heat for domestic purposes. We are a community in reality and not a number of watertight compartments, and there is no possible doubt that the community would burn much less coal, make much less smoke and have much more comfort if the various authorities concerned could be induced to sink their private interests and work for the common good.

Mr. F. Biggin: These two papers were prepared especially to demonstrate that the exhaust steam from electricity generating stations can be utilized for the warming of surrounding buildings. A very strong case is made for the installation of similar systems in towns where the conditions approximate to those set out in the paper. In this instance the generating station is in a fairly congested area and the buildings adjacent are of such size that it requires a considerable amount of heat to warm them. Thus there are ideal conditions for using what was otherwise a waste product. It may be argued that these conditions could not as readily apply in other towns, but it should be borne in mind that heated water can be circulated for miles in properly insulated pipes, with very little heat loss. Thus it would be possible to heat a number of buildings within a fairly large radius of the generating station. It has been argued that if the exhaust steam were used for warming buildings the boiler power would have to be very largely increased. Granting this, it would eventually result in the scrapping of an equal amount of boiler power elsewhere, as the warming by the exhaust steam would displace the boilers which had hitherto been employed for this purpose, so that it would not mean increased boiler power really but only concentrating the present boiler power into one station. Surely that in itself spells economy. By displacing a number of smaller boilers, space, staff, chimney losses, maintenance costs, etc. would be saved. It should be the constant aim of the engineer to obtain as much heat energy as possible from the consumption of coal, and as we all realize the value of by-products in other directions we should certainly make the best use of the by-products of our electricity generating stations. I propose to give a few figures in connection with a heating installation at a poor-law institution, consisting of 17 blocks of buildings and covering 9½ acres. A complete system of lighting, power and heating has been evolved, with the result that a saving of £7 000 has been effected during the past year. This figure

was arrived at by taking the actual weights of fuel used before 1914 and costing at current prices, and then comparing the same with the amount of fuel used now. The Institution which I am quoting is a combination of a workhouse, infirmary, and some cottage homes. Originally each of these buildings was warmed by a separate heating installation with boiler and radiator and pipes, etc. The hot-water service was from steam-heated calorifiers using live steam, and hot-water boilers. The lighting was carried out partly by gas and partly by electricity. It was decided to centralize the whole of this plant, and turbo-generators were installed, and the exhaust steam was taken through a battery of four calorifiers for hot-water service, and through two for heating. The whole of the independent boilers and calorifiers were scrapped. During the past 4 years only part of the reorganized plant has been working, but the saving has been such that the whole of the cost of the installation has been written off, and there is a surplus of about £1 000. This was done with a small 100-kW generating plant, but the principle is there, and it is only a question of degree for larger installations. I consider that a strong case has been made out for the better utilization of exhaust steam. In all cases where power only is required, pneumatics or hydraulics should be used, but if light or heat is also required a generating plant should be installed. We are just now engaged in the erection of a plant in which we propose to exhaust at 60 lb. in order to use the exhaust steam for further motive power and for heat in the process of manufacture. I consider that everything possible should be done to make use of the exhaust steam from all kinds of generating plants.

Mr. D. Brownlie: Mr. Haden has taken the efficiency of the steam boiler plant of the power station as 80 per cent. As a heating engineer, he is very generous to his opponents, the electrical engineers. Those of us who have had much experience in steam generation know that such a figure is absurd. The boiler plant of the average power station in this country is not running at more than 70 per cent efficiency, and that of many plants is below 60 per cent. In my opinion if half the money now spent on new plant were devoted to getting the best results from existing plant the country would benefit. Many electricity stations have not even water meters or combustion recorders in proper working order, and they have no idea of the cost of the steam which they generate. I think therefore that it would be much more correct in these calculations to take an average of 70 per cent boiler plant efficiency for electricity stations. It is quite true that there are many practical difficulties in the way of preventing the loss of the latent heat in condensing, but we cannot continue to waste 60 per cent of the coal in warming up rivers and canals. If we take the most efficient steam turbine of the largest size that can be installed, with superheated steam at 300 lb. pressure and 750° F., the figure for the performance is 17 000 B.Th.U.'s per kWh, and even if we get 15 000 kW with still higher pressures, 50 per cent of the heat of the coal is wasted in the condenser. In this country we burn 90 million tons of coal per annum for the one purpose of generating steam in stationary steam boilers, i.e. about 47½ per cent of the total amount of coal burned in Great Britain. We have no proper engineering census, but it will not be an exaggeration to say that one-third, or 30 million tons, is used for low-pressure process work, at an average pressure of certainly not much more than 40 lb. If we were to install plant in these works and generate steam at 160 lb. pressure and then pass it through engines or turbines, and use the exhaust steam for low-pressure purposes we should have 3½ million h.p. available, which is now being thrown away, representing about one-third of the power of the whole country. I submit that as a business proposition it would be far better for these works to use pass-out plant instead of spending millions of pounds on super-power stations in which 60 or 70 per cent of the heat in the coal is used to warm the rivers. The chief problem of the electrical world to-day is to find in Great Britain a river big enough to absorb the enormous heat wasted from super-power stations, and at the same time remain cool enough to maintain sufficient vacuum. Mr. Haden does not give instances of how much the power output will be reduced by converting a station from condensing to pass-out turbines. One of the objections which electrical engineers might raise is that it will result in such an enormous reduction in power. I have calculated that in a 20 000-kW station with steam at 200 lb. pressure and with 200 degrees superheat, and turbines at 28¾ inches vacuum, if the plant were converted to the pass-out principle so as to prevent the latent heat of steam loss, the power output would be 7 000 kW. That does not necessarily mean that the pass-out scheme is wrong, and I submit that it would pay this country far better to make the station still larger in those particular cases and raise the load to 20 000 kW, and sell the heat in the exhaust steam in place of wasting it in the river, provided, of course, that the position of the station was suitable, and the exhaust steam could be sold. There are quite a number of places in this country where this would be the best proposition. In my opinion Great Britain is essentially a country where we cannot generate power by one particular method. Electricity enthusiasts in this country are always thinking of large sums of money for super-stations, to the exclusion of every other method. The way to get national fuel economy is by a combination of many methods of power generation, including central heating, the efficient use of blast-furnace gas, the low-temperature carbonization of coal, and the development of the Diesel engine, which is far more efficient than any condensing steam turbine, no matter how big and expensive it may be. Electrical engineers, I think, have not raised one point, which may be regarded as a minor objection to the principle of central heating. This method of heating has been in vogue in the United States and Canada for 40 years. The American lives in a very hot house and is accustomed to breathing warm air. This is not as healthy as breathing cold air and heating the body by means of radiant heat according to the British method. In my opinion the ideal system of heating houses in Great Britain is central heating to raise the temperature of the house to a tepid point, then to have gas cooking, electrical lighting and, in the rooms which are in constant

use, open fires with low-temperature fuel. This would combine the advantages of central heating with the direct radiant-heat method for the damp climate. Another objection raised against central heating is the digging up of the streets. This difficulty must, of course, be overcome. Some speakers in the London discussion raised the objection to central heating of the heat lost or dissipated in the steam pipes by conveying steam a long way, but this problem was solved in America years ago. To-day the average loss in a modern central heating installation in America, using as an insulator a layer of air around the steam pipe which is surrounded by wood or concrete and buried, amounts to only 0·04 lb. of steam per square foot of surface. The life of such an installation is at least 20 years and the pipes can convey the steam up to 1 mile. Many similar jobs have been carried out, to my knowledge, on these lines.

Mr. H. C. Lamb : In common with other speakers I hope to see a considerable extension of the central heating system in Manchester on the lines advocated by Mr. Haden. His paper is extremely stimulating, but some figures which are very wide of the mark have been included. It is a fact that in this district there are several stations, 20 years old, operating at an efficiency of 12 to 15 per cent. Station engineers in this part of the country do not conveniently ignore all the power used on the works in arriving at their efficiencies, which are based upon actual output and not on units generated. If Mr. Haden were to order coal 12 months in advance for one of the new, very large stations, on the basis of the figures given in his paper, he would probably find at the end of the year that he had ordered 250 000 tons too much. Comparing the power plant of 30 years ago with the best that can be manufactured to-day, the coal consumption per unit has been practically reduced to one-quarter. If that rate of progress can be maintained during the next 30 years we shall do extremely well. I quite agree with Mr. Haden in his proposals for the use of the old stations, but there is no justification for the idea which some of Mr. Haden's supporters have put forward, i.e. that stations in industrial areas can be made to distribute heat so as to balance exactly the electrical load and the heating load. Mr. Pearce has already referred to the impossibility of doing this in Manchester and I should like to give one or two illustrations. If we take a typical cotton mill with a load of 1 000 kW, the steam used for heating the mill is only about 3 000 lb. per hour, i.e. 3 lb. per kW. If we take a large engineering works with a load of 1 000 kW (which covers a greater area in proportion to the power than a cotton mill) the steam for heating would be about 8 000 lb. per hour, i.e. 8 lb. per kW. If we take a large block of warehouses and offices supplied with both steam and electricity, the maximum demand for electricity is 300 kW and that for steam is 9 000 lb. per hour, i.e. 30 lb. per kW. There, of course, we get very much nearer the balance required, but still it is far from the 115 lb. per kW quoted by Mr. Haden. I think he would say that the centre of Manchester is probably one of the very best areas to develop with central heating. The radius of the electricity supply from the city stations is about ¾ mile. In the winter the demand for electricity approaches 20 000 kW, and the boilers have a capacity of about 300 000 lb. per hour. Supposing that this area could absorb the whole of that steam for central heating—and it is not at all likely that it would absorb more—then, dividing the 300 000 by 115 lb. per kW, about 2 500 kW would be obtained; so that 16 000 to 17 000 kW would have to come from some other source, presumably the condensing station. Of course, if we had new stations using extra-high-pressure steam, with turbines exhausting at 60 lb. pressure, the result would come out at about 30 lb. of steam per kilowatt-hour. That figure approaches more nearly to a balance but the trouble is, as Mr. Pearce has said, that the two demands do not coincide. Another most important point is that in the summer the demand for steam heating falls to about 10 per cent of the winter demand, but in an area like Manchester the electrical summer day-load on the generating stations, compared with the winter day-load, is 85 per cent, so that it is utterly impossible to make the two demands balance in an industrial area of this kind. We are particularly indebted to Mr. Haden for pointing out that this service of exhaust steam is worth 4s. per 1 000 lb. If that be made a standard price for this country I am sure that all station engineers will be quite prepared to do business, but it is not advisable to talk about the steam for heating as "waste heat," because people get the idea that they should be supplied with waste products at little or no cost.

Mr. W. N. Haden : In most of the stations of the National District Heating Association of America—it depends upon the geographical position with regard to their coal supply—the charges per 1 000 lb. of steam measured by the condensate begin at about 4s. for the first 10 000 or 20 000 lb. per month and then come down as the loads go up to from 100 000 to 500 000 lb. per month to about 2s. 6d. for these large users. The commencing price varies from 3s. to 8s., according to district and size of plant. One reason, I think, why the heating engineers suggested the joint meeting in London was that we felt that if this matter was to be helped forward electrical engineers must co-operate with the heating engineers. I look upon the electrical engineers as the most suitable people to have charge of this work in the municipalities, and that any heating question which may come up should be connected with the electrical work and come under the charge of the electrical station engineers. I mention that particularly because in the early days it was thought we were in conflict with the electrical engineers and wanted to oust electric heating. Electrical heating certainly has its uses, especially for local application, e.g. heating beds in hospitals. An ideal central power station would include on one site the electrical supply, the gas-works, the heating and destructor plants, and if, as has been suggested, the coal could be carbonized before use, perhaps we could then get the maximum possible efficiency. In a large city recently a scheme was wrecked entirely because neither the gas engineers nor the electrical engineers would install their plant unless they had the monopoly of supply. If we could have co-ordination it would also help in regard to the

question of the cost of subways, because they would all radiate from the same centre and the same subways would carry all the mains. The cost of the subway would be then reduced. In a new district which is going to develop, the cost of a subway for the load at first required would be very high. In an old town the other difficulty is met with, i.e. that of congested mains in the street. These difficulties are perhaps great, but I think they may be overcome if we have the energy and if commercially it can be found to be a paying proposition.

Mr. A. B. Mallinson : I think that the papers vindicate absolutely the contention, often disputed in the past, that for works where there is a big demand for heat for manufacturing purposes it pays to generate power and use the steam afterwards. Notwithstanding that, it is extremely surprising to find how many such works still continue to use condensing steam engines for generating power, and separate steam from the boilers for heating purposes. If there is a field (and these two papers have shown that there is) for supplying heat from a power station, where there is the difficulty of getting mains through the streets to supply that heat, surely there is a perfect case for the retention of works power plants where heat and power are required in the one building. I should like to add the paper mill to the classes of work quoted by Mr. Lamb. A paper mill taking a load of 1 000 kW would have a heating requirement of at least 40 000 and probably 50 000 lb. of steam per hour, and what is more important—I would emphasize this particularly—it has a 132-hour-per-week load factor, and the heating and power demands are practically constant throughout the week. It seems to me that the first difficulty likely to be met with in these combined stations is the load factor, which Mr. Pearce put forward. The next is the pressure factor. For the heating of buildings the heating system can be laid out pretty well on a standardized pressure, but as soon as the steam is used for manufacturing purposes further difficulties will be experienced. For instance, Mr. Whysall mentions 2 lb. pressure. This pressure is quite useless for any manufacturing process. In paper mills where the steam is used for grass or straw boiling purposes, a pressure of 40/60 lb. is common, and even for purely drying purposes the very lowest that can be used is 10 lb. at the works. The station pressure would have to be set initially at a sufficiently high figure to cover these possible connections to the network. I think that the price of heat for manufacturing must be coupled with the price at which the power is to be supplied. That is a most important factor, particularly in considering the new industries which might be placed, as Mr. Haden suggested, close to the super-power station. If a modern paper mill were erected adjacent to, say, the super-power station at Barton, and power were supplied at ½d. per unit and heating at 10d. per 1 000 lb. it would cost them about 50 per cent more than they could generate their own power and heating for, allowing 10 per cent interest and depreciation on the capital outlay they would have to incur. On the other hand, money is scarce, and it will probably be scarce for manufacturing requirements for some time to come. If these papers do achieve no other result they will call the attention of those interested in the installation of these big industrial propositions to the fact that they can put down their mill near to a power station where they will be able to get both power and heat provided and so enable their capital outlay to go further in installing their true manufacturing plant. The figures given of installations actually in operation are very interesting, but they are very small compared with those obtained from time to time in manufacturing works where there is a big demand for steam night and day throughout the year for heating and process work. Apart from the question of new factories, and possibly a few existing works situated near existing power stations, I think the developments in this country on heat-economy lines will be on the principle of installing self-contained power-heat plants. I installed such power plants in calico printing and paper mills 20 years ago, and these are still in full commission and giving excellent results.

Mr. W. Eccles : In Fig. B, which shows the losses in a power station, the ordinates are B.Th.U.'s or watt-hours, and the abscissæ temperatures in degrees F. If we start with 100 B.Th.U.'s of heat, the question immediately arises : What is the value to the power station engineer of that heat in different parts of the plant. It is, in my opinion, the percentage that could be turned into work. The curve "potential work value of 100 B.Th.U.'s" shows the amount of that heat which might be turned into work at any particular temperature. This is the efficiency of the perfect engine, receiving heat at this temperature and exhausting at atmospheric temperature, viz. 60° F., as given by the expression $(T_1 - T_2)/T_1$, where T_1 is the initial absolute temperature and T_2 the final absolute temperature, in degrees F. The ordinary power station burns coal and, assuming 100 per cent thermal efficiency of each part of the power plant, if coal could be burned perfectly it would give a temperature of about 4 800° F., but as it is not burned perfectly in the furnace it gives a temperature of about 2 500° F. The heat in the coal has fallen from a possible 4 800° F. to 2 500° F., and in losing that temperature it has lost, as will be seen from the figure, 7·5 B.Th.U.'s in potential work value, or in other words the opportunity of converting 7·5 of the total number of B.Th.U.'s into work has been lost. Mr. Baumann refers * to this loss of potential work value although the total amount of heat is unchanged, as the "degradation" of heat. The furnace passes heat at 2 500° F. to the boiler, which in turn passes it to the turbine at 650° F. Thus the boiler has accounted for a loss of 29·5 B.Th.U.'s in potential work value. The turbine engineer starts here, having been told that he has been given 100 B.Th.U.'s, but, as will be seen from the figure, the maximum potential work value of this is 53 B.Th.U.'s. The turbine takes the steam at this temperature (650° F.) and at a pressure of, say, 250 lb. per square inch (gauge) and 244 degrees F. superheat. Owing first to the fact that this temperature has been obtained by superheating the steam instead of by increasing its pressure, and secondly to the fact that multi-stage feed-heating is not fitted to the turbine, the engineer is deprived of a further 18 B.Th.U.'s in work value, so that the actual work value of this heat

* *Engineer*, 1920, vol. 130, p. 150.

is 35 B.Th.U.'s. If it were possible to use this steam in a perfect turbine, i.e. one having a thermodynamic efficiency of 100 per cent but not having multiple-stage feed-heating, and exhausting at 80° F. (allowing cooling water. Applying these work values of heat to an ordinary commercial plant where parts are not working at 100 per cent thermo-efficiency, the resultant losses are as shown in the following table:—

Part of plant causing loss	Temperature	Potential work value of 100 B.Th.U.'s	Reason for loss	B.Th.U.'s passing on from B.Th.U.'s initially	Potential work value of B.Th.U. passed on	Loss caused by part pursuing heat instead
	F.	B.Th.U.'s		B.Th.U.'s	B.Th.U.'s	Per cent
Coal	4 800	90	2 % heat in coal lost in ashes	98	88·2	11·8
Furnace	2 500	82·5	2 % heat in coal lost in radiation	96	79·2	9·0
Boiler and economizer ..	650	53	21 % heat in coal lost in radiation, chimney, etc.	75	39·8	39·4
Superheated steam and absence of multi-stage feed heating	650	35	No loss	75	26·2	13·6
Turbo-generator	80	3·7	80 % thermodynamic efficiency (T.D.E.) (From diagram, 100 % T.D.E. turbine turns 31·3 % B.Th.U.'s into electrical energy or 19·36 B.Th.U.'s in 75 B.Th.U.'s for 80 % T.D.E.)	75—19·3 (= 55·7	2·06	24·26 (19·36 to electrical energy; 4·9 turbine losses)
Condenser	60	0	No loss	55·7	0	2·06
			Total			100

20 degrees F. loss in the condenser), 31·3 B.Th.U.'s could be converted into electrical energy. The remainder of the heat (68·7 B.Th.U.'s) is passed to the condenser at 80° F. At this temperature the potential value of

The degradation losses do not indicate inefficient design, but are primarily caused by the lack of better materials to withstand high temperatures. The thermal losses are, however, largely in the hands of the designers

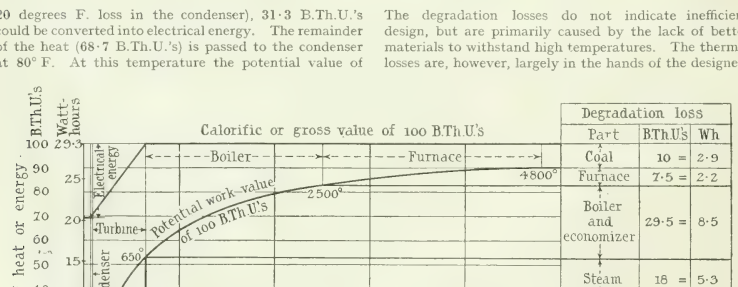


FIG. B.—Valuation of heat.

100 B.Th.U.'s is 3·7 B.Th.U.'s, and from this it is clear that the heat passed to the condenser (68·7 B.Th.U.'s) is worth 2·5 B.Th.U.'s. This loss is due to transferring the heat from the exhaust steam into the and purchasers. The difference between the percentage of heat turned into work given in this table and those quoted by Mr. Haden is due primarily to load factor and partly to obsolete plant and inefficient operation.

The boiler efficiency of 80 per cent given by Mr. Haden is really the best efficiency of the boiler, the working efficiency being under the best average conditions more nearly 75 per cent.

(*Communicated*) : The above remarks represent only what happens when coal or other combustible is burnt to produce power. If we look at the question of burning coal, etc., to produce heat, the problem assumes quite a different aspect. The value of heat as such is 100 per cent at all temperatures above that at which it is required by the particular process, and below that temperature it has no value except for pre-heating. Considering the heating question, it is clear that the duty of the heating engineer is to conserve heat as far as possible by reducing radiation losses to a minimum, reducing the amount of heat required by the process, and arranging for a suitable combination of heating processes in series, so that the heat rejected from one process is suitable for the next, e.g. the case of multiple-effect evaporation plants, etc. As the majority of heat-treatment processes are carried out at either very high temperatures of, say, 2 000° F. for metals, etc., or at 220° F. or lower, it will be seen that there is a vacancy in the temperature range very suitable for the conversion of some of the heat into power without detracting from the heating value of the heat used, except by the comparatively small amount which has been converted into power. If we now consider the heating and power problems together it will be seen that the heating engineer has to study, in addition to the conservation of heat, the question of the degradation of heat, which means that for the low-temperature processes the process temperature must be kept to a minimum and temperature-drops due to heat transmission, distribution or transference of heat from one medium to another must be practically eliminated. If a table of losses were made up for a combined power and heating plant as has been done for a pure power plant, and if the thermal and degradation losses for which the heating engineer is responsible were expressed as a percentage of the power value of the heat in the steam as it could be supplied to a turbine, it would be seen that the heating engineer is probably responsible for a much greater avoidable waste of potential power than the avoidable waste of heat for which the power engineer is responsible. The heating engineer has the advantage over the power engineer in that he has practically no limitations due to the lack of better materials to withstand higher temperatures.

Mr. A. Stubbs : Mr. Whysall directs our attention to a most promising field when he refers to the generation of electricity at a point where there is a bulk demand for low-grade heating steam. In nearly all these cases it is obviously a much better proposition to transmit electricity rather than steam, and it will often happen that the exhaust-steam stations may be used as sub-stations for the electrical load within the immediate neighbourhoods, thus effecting a probable saving in the cost of transmission, as well as improving the regulation. I am glad to have Mr. Whysall's assurance that there are no technical difficulties. After giving considerable attention to the subject, I am in complete agreement, for everything is very simple, and there is much profit to accrue. The difficulty lies in the allocation of this profit. It is in the treatment of this part of the subject that the paper is deficient, for a general ruling cannot be expressed by means of figures, rates of charges, etc., and all that can be done is to state the principles upon which the consideration of a particular case can be based. The case must be stated with the liabilities of all parties definitely defined, and the profit shown must be allocated according to the risks borne by the parties to the contract. The suggestion that the profits shall be equally divided may appeal to an Electricity Committee where there is a large socialistic representation, but it is not practicable. In other words, if the supply undertaking is prepared to put up a station to supply heating steam they should be entitled to the whole of the profit. On the other hand, if the industrial concern erects the station, installs the plant and runs it then they may in turn reasonably expect to receive the whole of the profit. The conclusion therefore is that the profit must be the cost at which the main station could produce the particular units generated at the exhaust-steam station, full account being taken of the fuel, capital, rates, taxes, transmission and other charges, less another sum representing the actual cost of generating the units at the exhaust-steam station where also complete account is taken of all charges, but in this case the fuel costs will be low, whilst there will be little or no charges for boiler plant, condenser, cooling-water plant, etc. We have recently had sufficient experience of the super-power station to realize its shortcomings, and there will probably be a reaction against the super-power movement arising out of a recognition of its limitations, the universal shortage of capital and the general departure from the centralized control which reached its climax with the end of the war. The present subject is part of a de-centralizing movement and brings with it many marked advantages which must make themselves felt as an economic force, so strong that it cannot be restrained. It is, however, within the power of the station engineer to render a service of public utility by retaining a central control over the working of these stations, or even undertaking similar responsibilities with regard to the supply of low-pressure steam as is done when supplying electricity. Much will depend upon the way in which the problem is treated, and central station engineers have a means either of supplementing their existing plant or, alternatively, of inviting competition. In order to crystallize our ideas a concrete example will be of service, and for this purpose there is an excellent example within our own area. Let us suppose that it is required to produce 2 000 tons of sodium chloride per week, i.e. approximately 45 000 lb. per hour, which corresponds to approximately 45 000 lb. of steam per hour through the turbine. If the turbine consumption is 30 lb. per kilowatt-hour this corresponds to 1 500 kW. That such a station should by some unnatural growth have expanded to a capacity of 30 000 or 40 000 kW is of interest, but its subsequent failure or otherwise must not be allowed to detract from the elements of success which were present in the first scheme. It is worth notice that a single sugar refinery may have a generating capacity almost equal to twice the above amount. An industry of this kind is unfortunate when it is so situated that a large power supply is not available

in the immediate vicinity, as in this case it usually involves the installation of an expensive and comparatively cumbersome reducing pressure turbo-generating plant in order to ensure continuity of electric supply. The back-pressure turbo-generating plant is cheaper and in every way more desirable. The operation of exhaust-steam stations when using back-pressure turbines might very well be made automatic, and in this connection I would draw attention to the following points: (1) The speed is determined by the frequency of the main supply; (2) the voltage is determined by external conditions, and (3) the load is dependent upon the quantity of steam available. It will be evident that the most satisfactory automatic operation is not likely to be obtained by using an automatic voltage regulator to control the alternator field. A much better plan is to install a power-factor regulator, which would so control the alternator field that the power factor of the set would be maintained at a definite figure, say 0·8, no matter what the external conditions might be. So far as I am aware this instrument is not yet being manufactured in this country. A further possible use for this apparatus is in connection with house turbine sets running in parallel with the main busbars and the load on which is subject to thermo-static control, in accordance with the feed-water temperature.

Mr. F. H. Whysall (*in reply*): Mr. Pearce puts the case accurately, and I quite agree with him that on theoretical grounds few would find it easy to frame a case against the combination of heating and electrical loads. It is also true that only those who have tried, or are interested in, a scheme, fully realize the many practical difficulties. I agree also with his criticisms of Mr. Haden's figures, and I admit that in the figure of 10d. per 1 000 lb. with coal at 10s. per ton Mr. Pearce's criticism is just, no allowance having been made for increased capital charges or operating wages. Mr. Pearce's figures for the cost of subways agree very closely with the actual cost of tunnelling work at present being carried out under my supervision.

Mr. Frith thinks that a municipal liaison officer is required to bring about co-ordination in our communal life, and I would suggest that the electrical engineer is trying his hardest to fill the office mentioned and that he is naturally the municipal official best fitted by circumstances for it.

Mr. Brownlie attacks vigorously the principle of the establishment of super-stations to the exclusion of every other method. I am of the opinion that he is distinctly unfair in the assumption that electrical engineers ignore in any way the question of national fuel economy and alternative methods of power generation, including central heating, the efficient use of blast-furnace gas, the low-temperature carbonization of coal, and the development of the Diesel engine. In fact, I would emphasize that electrical engineers spend a very great proportion of their professional time in trying out these possibilities, and that they can be relied upon to be the first to recognize commercial possibilities when they exist. He also states that we have no proper engineering census. That is true, but I think it should be emphasized that such census as we have is the work of the electrical engineers of the country, and that the economies in fuel already due to the efforts of the electrical engineers through their supply-station experience represent, directly or indirectly, probably a larger amount of fuel than there is a possibility of saving in the future. I should also like to reiterate in reply to Mr. Brownlie's remarks that where a public supply of electricity is available from a so-called super-power station, it does not pay the manufacturer to put in reducing pressure plant for the generation of his own electricity, unless he can at the same time arrange to sell the surplus energy.

Mr. Lamb emphasizes the improvement in the economy of operating power plants in the past 30 years and points out that the coal consumption per unit has been practically reduced to one-quarter of the figure obtained 30 years ago. He suggests that if this rate of progress can be maintained during the next 30 years we shall do extremely well. He also gives some illustrations to disprove that stations in industrial areas can be made to distribute heat so as to balance exactly the electrical load and the heating load, and that the demands coincide. These facts are not in dispute and only serve to emphasize the contention that each case should be considered on its merits and that much is to be gained by co-operation. With regard to his criticism of 4s. per 1 000 lb. for exhaust steam, I would point out that I understood that this figure was put forward for coal at 40s. per ton and that 10d. per 1 000 lb. with coal at 10s. per ton is approximately the same when proper adjustments are made for the difference in the cost of fuel between 10s. and 40s., and a proper allowance is made for increased capital charges and operating wages which are coincident with such an abnormal price as 40s. per ton. I agree with Mr. Lamb that it is not advisable to use the term "waste heat" as applied to exhaust steam.

Mr. Haden gives some figures relating to the charges for heating measured by condensate in American practice. These figures are very interesting as illustrating the adoption of a method of charging which is a recognition of what is known to electrical engineers as the Hopkinson principle. (It was Dr. John Hopkinson who first pointed out the necessity for separating charges for a supply between standing and running charges.) He emphasizes the necessity for co-operation between municipal departments and suggests that the electrical engineer is the most suitable official to bring it about.

Mr. Mallinson states the case for the paper mill and emphasizes the constancy of the heating and power demand. He also refers to the 2 lb. back pressure mentioned in my opening remarks as being a reasonable limit for the supply of exhaust steam for heating purposes; he is evidently under a misapprehension with regard to this as he compares the figure with that necessary for industrial processes. My experience is that the pressures for industrial processes vary from 5 to 80 lb., but I should like to point out that so far as my own experience is concerned the pressure used is nearly always higher than is really necessary and this is due to a desire either for a working margin or to the fact that distributing pipes are not large enough. The case of a paper mill is quite distinct from the proposal to

supply exhaust steam for heating purposes from the generating station. In the case of a paper mill, a reducing pressure turbine for generating electricity would be put down at the paper mill and an outlet found for any available surplus energy. I would repeat that, from my own personal experience, where a public supply of electricity is available it does not pay a paper mill to put in reducing pressure plant for the generation of electricity unless at the same time the sale of the surplus energy can be arranged.

I agree with Mr. Eccles that the power station engineer works very economically with the heat range available, and that he has limitations which do not affect the heating engineer working with lower pressures. The real question is, of course, a commercial one, and in each case it is necessary to consider how much of the heat can be used profitably.

Mr. Stubbs thinks that where the supply undertaking is prepared to put up a station to supply electricity and steam, they should be entitled to the whole of the profit, and, on the other hand, the industrial concern, if they erect the station, may reasonably expect the whole of the profit. In my opinion, Mr. Stubbs is wrong in his attitude with regard to the appropriation of profits between the parties, and I would say that in my experience the only practical working arrangement is one which divides the profits approximately equally between the parties.

ADDRESS TO THE LONDON STUDENTS' SECTION

By J. S. Highfield, President.

(*Address delivered* 31*st March*, 1922.)

A Story of Trade.

It is 14 years since I had the pleasure of addressing the Students' Section. I chose as my subject on that occasion "The Responsibility of the Engineer," and since that time I do not know that the responsibility has become less important. Much has happened since; great changes in thought have occurred, and we have fought and won the Great War, and a noble part indeed did the students of this country play in it.

I always think that the term "student" describes the most excellent of all men; it indicates a humility of spirit, a desire to learn. Strangely enough, we often find that those who are not described by the term exhibit these qualities more than those who are so described.

Engineers, no matter by what description they go, must in fact remain students, first because the science on which their business rests is ever advancing, and secondly because all engineering work is team work, not only on the designing side, but later on also in application. Consequently all engineers in any position of command or trust must acquire a clear knowledge of human nature in all its changing aspects; and, since all Students of the Institution look forward to filling such positions, it is essential for these reasons that, no matter to what degree of eminence they may rise, they remain students in fact.

The present times are most difficult for everyone and, I think, not least for Students. I can well remember in my own college days the anxiety involved when nearing the end of my time as to when and where I should get my first job. I fear the anxiety is even greater to-day and it will remain so until trade improves.

The reasons for the present trade depression are many and the whole subject is too complex to be treated conveniently in a short address. It is also a subject which many of you may think is outside the range of engineers. I do not hold with this doctrine. I think that a subject of such vital importance is essentially one in which engineers should at least take a lively interest and which they should study; and I should like to see the engineering schools pay attention to the broad principles of trade and finance.

I shall return to this subject, but I want first to consider the changes that have taken place in engineering, and particularly electrical engineering, during the last 80 years. I want to get back to first principles and to find, if we can, some lesson from the study. The task is the easier because the Commemoration Meetings have provided a fund of first-hand information about the beginnings of electrical engineering, a history which when reproduced in the *Journal* will, I am sure, well repay careful study.

Before Volta's discovery of the primary battery there was no electrical work actually of use to mankind; there were a few men gifted with the love of natural research who tried to wrest from Nature some of her secrets, and that was all. Volta's discovery gave us relatively large currents at low potential, and Oersted, using the earliest magnetic instrument in common use, the suspended magnetic needle, made the discovery that a wire carrying a current influenced the magnetic needle. These experiments led up to the marvellous discoveries of Faraday, among the most fruitful discoveries made by man. These discoveries have been admirably demonstrated in Professor Fleming's recent

lecture * and demand no further description from me to-night.

Faraday's discovery of the means for transforming mechanical into electrical energy was made in 1832, and the first useful dynamo about 1870. Observe the long period required to give any practical value to Faraday's work. The number of men then working at the subject of electrical engineering was very small, and until much later there were no training schools for engineers.

The electric telegraph was developed quite apart from Faraday's work; it arose from the discoveries of Volta and Oersted, helped on by Smee and Cooke and Wheatstone. The first telegraph was used in 1837, 17 years after Oersted's discovery. Again, note how long a time is required to give practical application to a scientific discovery. In 1876, Bell invented the telephone, one of the most amazing inventions in the history of man, from whatever angle it be viewed—whether from its usefulness, its simplicity or its wonder, the reproduction of the human voice by such simple means and with such tiny currents, or again as an extraordinarily delicate detector of changes in current strength.

We want, if we can, not only to see, as in a well-lighted picture, the wonder of these inventions, but to realize their effect on thought and action, and their compelling force on the students of those days. To this end it will be well to retrace our steps and consider the state of engineering generally before and during the time this work was accomplished.

Modern engineering took its birth from the practical development of the steam engine. It was invented in an elementary form for pumping purposes by Savory, improved by Newcomen, made an efficient machine by Watt in 1765, and finally built in a commercial form by Boulton and Watt in 1775. It is interesting to recall that the first cotton mill erected near Manchester in 1780 was driven by a Boulton and Watt pumping engine, pumping water over a wheel to give circular movement.

Then followed the work of Stephenson, Nasmyth, Maudsley, Clement, Whitworth and very many others, men whose lives should be read by every student. These pioneers mainly trained their own men, and Whitworth in 1868 founded his scholarships to enable students to gain the manifold advantages of theoretical as well as of practical training. Nasmyth made arrangements to train men in his own works, and there followed the application of the apprenticeship and pupil systems of training in many engineering works.

These methods served well enough in the early days and, in fact, were all sufficient before the advancing art of design made necessary the application of accurate measurement and of detailed research into matters like the strength and characteristics of materials. The problems arising from these necessities led to special researches being started for their solution, and side by side with the practical engineers there marched the men who worked at what is known as pure science, and also the theoretical investigators who used as their instrument mathematical analysis. It is true that there was much overlapping in all this work. Watt himself gave much time and contributed to all branches, so did John Hopkinson and many others. Mechanical and steam engineering called for the work of Young, Joule and Fourier, but with the growth of electrical engineering the needs for yet more careful study of theory and of extensive and accurate research became of rapidly growing importance. This movement resulted in the engineer's job becoming increasingly complex and led to the establishment of training schools, of which University College (London), King's College, and Faraday House are notable pioneers, where the theoretical side and some of the practical side of engineering could be taught. Colleges and technical schools for the teaching of science and engineering have steadily increased in numbers and there is no doubt that the increased knowledge resulting is of the greatest benefit to the nation.

The difficulty at the present time is to absorb into industry all the men available, and with them all the skilled and partly skilled workmen who to-day in lamentably large numbers are out of work.

This fact brings me back to the matter of trade referred to at the beginning of my Address, a matter to which I am sure men trained as engineers can usefully apply their minds. Trade consists in buying and selling, in exchanging one sort of goods or services for other sorts; we trade on a small scale when we sell directly or indirectly to few, and on a large scale to many. All trading involves risk, but also offers large rewards. In old days the trader and merchant were obliged to take large personal risks. The merchants were often the captains as well as the owners of their small vessels; they risked all, vessel, cargo and life, in carrying on trade. Try and visualize if you can the difficulties and heroism of those early traders and the romance in winning from land and sea by toil and hardship the fair kingdom we call Great Britain. During the ages the engineer has steadily improved all these conditions and has rendered life more efficient and less full of hardship, but these efforts are made possible only by the successful trader who finds the money, the surplus of food and goods, which form the foundation of all progress.

So there are two broad classes of men, the traders, the masters who are able and willing to carry the risk inseparable from any venture and who in one way or another pay wages and salaries; and there are those who receive the wages or salaries and whose responsibility may be equal to that of the masters, but who have not the same risks to carry. The vast difference between these two classes is not sufficiently realized, and particularly it is difficult for the receivers of wages to realize the burden of responsibility borne by those who pay them. It is felt, and can be felt to the full, only by those who have known the anxiety of wondering how they can find the money to pay next week's wages and who know that, for want of it, they may be forced to dissolve an excellent army of men, or to lose excellent and valued assistants. In these hard times many have had this dire experience.

I incline to think that the training colleges tend to turn out men equipped rather as salary receivers than as salary payers, and at the present time it is the latter type of mind that is needed. Men are required who

* See page 379.

can create markets and start new ventures all over the Empire; men who will initiate new schemes and methods rather than those who seek a quiet, well-paid job. It is easy to say this, but the difficulty of execution is great; it has, however, been tackled in the past and it will be faced to-day and surmounted. We hear at times of emigration schemes. There are countries in our Empire with ample spaces and every condition suitable for new adventure, but casual emigration does not seem to me to be the best method of filling them. I should like to see a proper colonizing venture consisting of a number of picked men and women skilled in appropriate trades. These should take with them sufficient equipment rather on the lines of a polar expedition, but instead of proceeding to icy latitudes they should choose a more gracious climate where they could found another outpost of Empire, a new centre for Empire trade. In this way they would not only help themselves, but help the old country too. There is nothing new about the suggestion; it was used centuries ago by the Greeks, and the main difficulty is to find a really efficient leader on whom success depends.

It may be thought that a scheme of this sort is more suited to farmers than to engineers, and this is in a measure true because, of necessity, the farmer's work arises earlier than the engineer's. But, on the other hand, an engineer's training fits him to carry out a multiplicity of jobs and he has a practical desire to secure results, and therefore I venture to talk about it to you.

It is interesting to consider other countries; it is in fact a duty to try to realize the vastness of our Empire and to think of the many famous men who have taken part in its building. It is well and good to acquire the detailed knowledge necessary to an exacting calling. At the same time education is a far greater matter than the mere cramming for examinations; our Empire never would have been created solely by such learning, and in these days when leaders are sorely required I hope to see more attention given to wider and deeper matters.

The present conditions of trade are in some measure due to our own fault; they are partly due to the refusal of men to work hard and diligently. No matter for what reason a man fails to do his share of the common task the fact remains that, while he is idle, either he must starve or someone else's surplus must be used to keep him. Even while the surplus feeds him he is not happy, and what is to happen when the surplus has gone? To create a surplus everyone must work. The chance to work is the crying need of the times and we want pioneers to create the chances, but we must have too the willing men to take the chances and to use them to the full.

Given the chance and the diligence, in time the surplus comes from which can be provided more plant, more opportunity. That surplus is capital and it will always gravitate to those who are skilful and frugal. But the earning of a surplus leads also to the creation of credit, which may be defined as a belief in the future, a belief in the success of an individual or a group of individuals, and the credit so created tends to attract the surplus from other ventures.

Business is one of those things whose stability is due to movement; it cannot stand still and if it fail to advance it will certainly go back. Success, and the credit depending on it, are delicate plants requiring constant care. The violent treatment meted out since the war has damaged all business. First came inevitable disease, then the application of violent remedies, which the patient has miraculously survived. If he is left to himself I am sure he will recover and, with time and some protection, will regain more than his lost vigour. Business must be saved both from quack doctors and from strange nurses.

We all know that engineering is in a poor way at present, but let me give an illustration of a business which is still worse off. It may be useful as showing how one business depends on others and how one man's luck or misfortune is reflected on many others. If I fail to win a bet on the Derby myself, I like my friend to win one—he usually gives me a dinner.

I will tell you something about the industries of Cornwall by way of illustration. I choose that county because it is relatively self-contained and because, unfortunately, some of its industries have suffered very severely. The principal industries are fishing, agriculture, copper and tin mining, and the china clay trade, and supported on these are shipping, engineering works and the Electric Power Company.

Before the war all these trades were in a measure flourishing, shipping moved freely into and out of the ports of Falmouth and Fowey and the smaller ports of St. Ives, Hayle, Charlestown and Par. The Power Company, which has a very good modern station at Hayle and distributes power mainly by overhead lines all erected when plant was least expensive, was in a state of reasonable prosperity, placing every year a large sum to reserve and paying a safe dividend of 4 per cent. None of the traders was very rich but all were in a state of fair prosperity.

There are certain characteristics common to these four elemental trades: Each depends on winning from sea and land, food or material useful to man, thus the sources of wealth are clear. These sources are, first, the presence of ample raw material to be won, and secondly, the skill and energy of the men in obtaining as much as possible; and wealth obviously is created in proportion as the amount won exceeds the quantity necessary for the workers' own use.

It is again obvious that the quantity won by each man depends not alone on his skill and energy but also on the gear and plant he possesses to help and to make effective his labour.

All four trades, certainly before the war, were in many hands; that is to say there were, and there still are, many small masters. Neglecting the migratory steam trawlers which work from Newlyn for a season, the fishing is done mainly by men who own in whole or part their own vessels. The farms generally are small, 500 acres being a large one. The tin and clay mines generally are in separate ownership, although there was before the war some tendency to amalgamation, which the war period increased. This multiplicity of masters tends to an independent and responsible spirit; it tends also to greater knowledge and content-

ment amongst the men, because the sources of their pay are more evident than in great organizations. Against this spirit of independence and contentment there is a certain loss of efficiency and of material wealth, this applying more particularly to the mining industry.

The difficulty of balancing the advantage of contented workers on the one hand against maximum output and efficiency on the other is an interesting study and just now a most important one. After the Napoleon wars many conditions arose similar to those we know to-day. There came the necessity to produce more food, and more was produced until prices fell and the small farms were sold; and the necessity of high production resulted in the loss of yeoman farmers and small freeholders, all masters, and their conversion into labourers, who were necessarily wage-earners. Production of foodstuffs was increased to feed a rapidly growing urban population, but the loss of mastership and character to the agricultural population was severe. Cornwall is fortunate in retaining to-day a multitude of small independent farmers.

Let me describe these trades in a little more detail. Doubtless, farming is the oldest of them if gardening is included in the term. It must necessarily have been so in order that man could win his daily bread. I need not trouble you with any special description of farming conditions, but it is an interesting fact that, since the falling off in employment in the tin mines, many men have set to work to provide food directly by cultivating small holdings.

The fishing trade of this country is of great interest and importance and is one that repays study because it probably provided the first surplus, the first wealth, the first additions to the mere necessaries of life. Almost certainly it was the cradle of overseas trade which led eventually to that most wonderful creation—the British Empire. The Hanseatic league was founded on the herring fisheries of the Baltic and these men had to win freedom and the enjoyment of rights from Waldemar, King of Denmark. On their victory, and on the profits of the herring fishery, was founded the great league of Hansa merchants. Just as this great league was founded on the Baltic herring fishery, so are the herring fishery and the tin-mining industry connected in Cornwall. "Herring and tin" is a local saying. Often the same men worked at different seasons in both industries, and to-day the mine managers are "captains" and the secretaries or accountants "pursers."

The trade of the fisherman is an exacting one, calling for courage and involving above others risk to life and gear; it makes a brave race. Broadly, there are two classes of craft engaged in fishing; first, the large sea-going trawlers which keep the sea for weeks, fish on distant grounds and carry ice for preserving the fish; these provide the greater bulk, and it is interesting to reflect that our fresh fish in London may be many weeks old.

The smaller craft work drift-nets, trammels and seines, and long lines in their season and, besides these devices, the crab and lobster pots. The shell-fishing industry is of importance, as it provides a steady living for very many families.

The skill and knowledge of the fisherman are acquired in early youth; the ways of fish and their life histories are matters still only partly known and are constantly being investigated, but many of the working fishermen have a very accurate knowledge of the habits of life of fish coming under their immediate observation. They know how the mackerel swim up-wind and the herring down; how some rocks fish on the ebb, others on the flood. They know their way over the fishing ground by day and night, just as a miner knows his way underground. The value of the fishing trade is probably at least equal to that of the tin or clay mining.

The mines of Cornwall date back to very early times. Centuries ago the mining was for copper and the tin was won from alluvial deposits, but the copper is now mainly worked out and all the mines working produce tin. Tin occurs in lodes or pockets and, consequently, the chances of tin mining are considerable; there is a large element of chance in opening up new workings. The process consists in crushing the rock and washing the resulting fine powder over various devices designed to separate by gravity the heavy particles containing the metal from the rock; and there are further appliances designed for treating slimes containing the finest particles, matter in a colloidal form. The black tin after drying is run through magnetic separators to recover wolfram and manganese, and arsenic is won by roasting.

The variations in the complexity of different lodes is remarkable, some containing almost pure tin and some being very complex. In the early days these complex ores were of little use, but now they are the most valuable. The gravitation and washing process has been refined over ages until it is marvellously efficient. Nevertheless, there is still much tin washed into the sea and there is room for further research in methods of treating the ore.

The Cornish mines have sent skilled miners to all parts of the world. They were the home of the first steam engines; those of Savory, Newcomen and Watt were used in that order for driving pumps, and the Cornish pump is to-day a most efficient machine.

It was in Cornwall that Murdoch, working for Boulton and Watt, invented gas lighting, and his cottage, near Redruth, was the first example of the discovery that led up to the great gas industry.

The mines use electricity provided by the Power Company's overhead lines for pumping, stamping, winding, working air compressors and many other purposes.

The china clay or kaolin trade is one of relatively recent beginnings. This clay is a decomposed granite, a silicate of alumina, and was first used for pottery. It has grown in the last 150 years to a business greater than the tin-mining industry. The rock contains some 20 per cent of clay substance, varying in different districts in fineness and in colour from an almost pure white to pale yellow. Much of the clay is tinted with vegetable matter, iron and other materials; and some deposits are black from vegetable colouring. Some of these tinted clays fire perfectly white and some of the white clays fire yellow. Besides its use for pottery the clay is used for filling paper and other fibrous

and cellular materials. The output before the war was well over one million tons. The clay is won by washing over the face of the rock with a stream of water and picking the face, and in modern plant by hydraulic mining with pressure jets. The clay and water or slip are pumped to the surface, passed over obstacles and through channels called "micas," where the fine silica and mica are deposited.

From the "micas" the slip is run into tanks where the clay is allowed to settle and finally, when in a butterlike state, it is thrown on the floor of the "dry," where the bulk of the water is driven off by heat and the clay containing some 12 per cent of water is ready for sale.

In all these four trades you will find every sort of temporary device, every kind of clever expedient used to save labour, at small capital expense because all the traders are relatively poor but the skill of the workers is great. It is a splendid field in which young engineers may study, and the fact that Cornwall and the Camborne School of Mines have sent all over the world so many skilled miners is proof of its efficiency.

On these primary trades depend coal miners, rope and sail makers, ship-builders, carriers, manufacturers of agricultural and mining plant and, finally, the Electric Power Company.

Before the war, as I have said, all these trades were in a fair state of prosperity; now, owing to the failure first of tin mining and then of the export trade in china clay, all are in want. Coal is not wanted, the electric power output is reduced to a point where the Company can hardly meet working expenses, and all the subsidiary trades suffer. The failure is not, in Cornwall, due to strikes or demands for unpayable wages; the source of their wages is so clear that the men are fully seized with a rough knowledge of economics. The men were, and are, willing to work for any living wage, but there is no one to pay it. It is a grievous position and there is no very clear remedy. Until the American demand increases there can be no revival in china clay. The Americans may have gold but they do not want clay, and so the harbours are full of idle ships. The heavy taxes stop restoration because capital is wanted to re-start trade and the Government take in income and other taxes and in death duties the money, and with it the energy and boldness to face chances, that trade so badly needs.

Generally speaking, the man who makes a safe investment does not really help trade; primarily he provides for his old age. The essence of trading is adventure involving risk, and that risk is carried either by the man who trades with his own money or who by investing in ordinary shares helps others to bear the risk.

When we see Ordinary shares being asked for, we shall know that trade has begun to revive.

I suggest that a study of the history of trade is one full of use and interest. History is taught too much as a record of rulers, of kings, of ministers and of law-makers, rather than of the traders in whose interests many of our laws were made, and in fact, many wars fought.

Read of Simon de Montfort and the Wars of the Roses and the laws of Henry VII and of Stuart times in the light of trade. The histories of the city companies provide interesting and often exciting reading. The record of the lives of such men as Thomas Gresham and of Cecil Rhodes open up new fields for thought and for example in adventure and statesmanship. It is for the young men to remain students and to add to the greatness of our Empire by facing fortune and bearing the risks, aye and of winning the rewards, as in days of long ago.

DIRECTIONS FOR THE STUDY OF HARD COMPOSITE DIELECTRICS (INSULATING MATERIALS).

(Report received from the British Electrical and Allied Industries Research Association, 21st February, 1922.)

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Preface.

This Specification defines methods of test intended for use in the investigation of the mechanical and electrical properties of hard composite insulating materials. The clauses of the Specification are not intended as "acceptance" tests in the purchasing of such materials, although developments of some of them eventually may be capable of adoption for this purpose.

The methods of test have been defined only after a long series of trials, using a wide range of hard dielectrics. Materials were included having bases of vulcanized rubber, vulcanized bitumen, shellac, and synthetic resin respectively, amongst others, but the large amount of actual data collected in the course of the research is not incorporated in this Specification.

The adoption of the methods of test given here is strongly commended to manufacturers and to users of these materials, so that a uniform practice in tests of this nature may be established. It is anticipated that if tests such as these are generally applied in Works Laboratories and elsewhere for the purpose of studying composite insulating materials, considerable improvements in quality will result.

The Director of the E.R.A. will value comments and criticism from those who have occasion to use any of the tests given in this Specification.

Introduction.

Hard Composite Dielectrics (Insulating Materials), for which the tests given in this Specification are applicable, comprise the following :—

Vulcanized * rubber,
Vulcanized * materials other than rubber,
Unvulcanized materials,

whether moulded to final shape, or in forms such as sheet, rod, or tube from which parts may be machined.

This Specification defines methods of testing such materials with a view to ascertaining their electrical and mechanical characteristics, and suitability for different classes of service.

For the purpose of the complete Specification the following characteristics, which are not dealt with in this Specification, will be subject to further research :—

Surface breakdown,
Dielectric losses,
Burning (inflammability),
Flash-point,
Fire resistance,
Action of solvents.

Limits to the values to be obtained in the tests are not set in this Specification for purchasing for particular purposes. Such limits may be derived later when more test-results are available, obtained by the methods herein defined. All the tests are suitable for investigating the characteristics of a particular grade of material, but the simpler tests are also suitable for checking individual consignments.

SPECIFICATION.

1. *Temperature Grading.*

Hard composite dielectrics are graded according to the temperatures they will withstand. If a material purports to have a given temperature grade it shall fulfil the requirements of Clauses 3, 5, 7, 8, and 10 of this Specification with respect to that temperature.

This Specification gives limits for the plastic yield test only (see Clause 7). This test has been found suitable for ascertaining the approximate grade temperature of most materials, but it should be understood that the grading as found by the plastic yield test has no value unless, at the temperature so determined, the results of the resistivity, electric strength, and other tests specified to be carried out at that temperature also are satisfactory.

* The term "Vulcanized" denotes that a chemical combination between sulphur and rubber, or other organic material, has been effected.

Electrical Tests.

2. *Conditions of Test.*

Tests are provided for machined and for moulded specimens under the conditions given below. These conditions do not apply in every case, but in order to demonstrate the general characteristics of a given material, tests shall be carried out under the conditions scheduled at the end of each clause to which they apply.

Except in the case of specimens to be immersed in oil [see (*h*) below], each specimen shall be given a preliminary treatment, being wiped carefully with petroleum spirit, specific gravity not exceeding 0·68 at 15° C.

(*a*) New condition, at a temperature from 15° C. to 20° C.

(*b*) New condition after remaining in a desiccator for 24 hours. The specimen to be tested whilst in the desiccator at a temperature from 15° C. to 20° C.

(*c*) New condition after remaining in a controlled atmosphere, relative humidity 80 per cent, for 24 hours. The specimen to be tested whilst in the controlled atmosphere at a temperature from 15° C. to 20° C.

(*d*) New condition after heating in an oven for one hour at grade temperature, preparatory to testing in the oven at grade temperature.

(*e*) After immersion in distilled water for one week at a temperature from 15° C. to 20° C., and afterwards removing surface moisture by wiping, preparatory to testing at a temperature from 15° C. to 20° C., within 10 minutes of removal from the reagent.

(*f*) After immersion in an approximately 10 per cent solution of salt in water for one week at a temperature from 15° C. to 20° C., followed by swilling with distilled water, and then removing surface moisture by wiping. The test to be made at a temperature from 15° C. to 20° C. within 10 minutes of removal from the reagent.

(*g*) After immersion in sulphuric acid solution (specific gravity 1·25 at 15° C.) for one week at a temperature from 15° C. to 20° C., followed by swilling with distilled water, and then removing surface moisture by wiping. The test to be made at a temperature from 15° C. to 20° C. within 10 minutes of removal from the reagent.

(*h*) After immersion in mineral transformer oil (specific gravity approximately 0·86 at 15° C.) for one week at grade temperature (but never higher than 100° C.) preparatory to testing in the oil at grade temperature (but never higher than 100° C.).

(*i*) After immersion in any other reagent which may be required to meet special conditions.

3. *Resistivity (Specific Insulation Resistance).*

(*a*) *Moulded materials.*

The resistivity of moulded material shall be tested on a specimen of the shape and dimensions shown

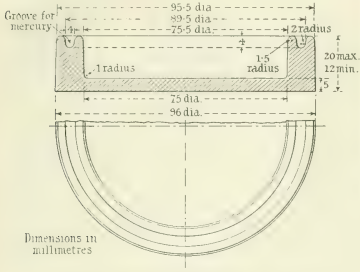


FIG. 1.—Specimen for Resistivity and Surface Resistivity Tests.

in Fig. 1, and set up generally in the manner indicated in Fig. 2.

The specimen shall rest on three pins fixed into the lower steel electrode, the top of the pins being 2 mm below the upper edge of the steel electrode. The internal diameter of the steel electrode shall be 98 mm, and the specimen shall be so placed that it does not touch the internal surface. The depth of the electrode in the inner cup shall be approximately 2 mm ; and the groove in the top edge of the specimen shall be filled with

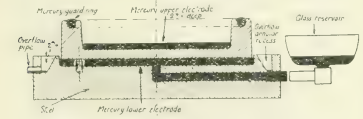


FIG. 2.—Arrangement of Specimen in Fig. 1 set up for Resistivity and Surface Resistivity Tests.

mercury. For temperatures not exceeding 100° C. mercury electrodes shall be used. For higher temperatures suitable fusible metal electrodes shall be used, if necessary, according to the temperature.

When the resistivity is calculated on the area of the upper electrode the result will be low owing principally to the increased area in contact with the lower electrode. The error will be approximately 15 per cent, and if this degree of accuracy is desired the result should be corrected accordingly.

(*b*) *Sheet materials.*

The resistivity of sheet material shall be tested when possible on a specimen of the shape and dimensions shown in Fig. 1. When it is impracticable to obtain a specimen 20 mm thick the overall thickness may be reduced to a minimum of 12 mm, the thickness of the base being 5 mm in every case. The other dimensions shall be in accordance with Fig. 1. The specimen shall be set up, with suitable electrodes as in (*a*), generally in the manner indicated in Fig. 2.

All the surfaces of the specimen shall be machined smooth, but not polished.

(*c*) *Rods.*

The resistivity of a rod shall be tested by boring out the rod so as to form a deep cup, and turning the outside surface. The dimensions shall be as shown in Fig. 3.

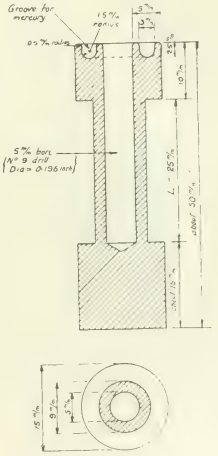


FIG. 3.—Specimen (machined from Rod) for Resistivity and Surface Resistivity Tests.

The specimen shall be set up for testing, with suitable electrodes as in (*a*), generally in the manner indicated in Fig. 4.

If L = length in millimetres,
r_1 = inner radius in millimetres,
r_2 = outer radius in millimetres,
R = measured resistance,
ρ = resistivity,

then

$$\rho = \frac{2\pi RL}{\log_e \frac{r_2}{r_1}}$$

If the specimen is made accurately to the dimensions shown in Fig. 3, then

$$\rho = 1{\cdot}07RL.$$

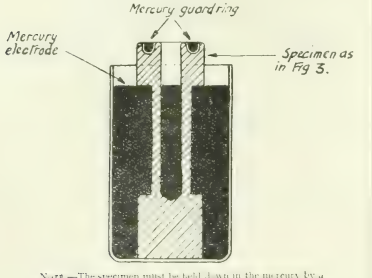
(*d*) *Tubes.*

For testing the resistivity of a tube, one end shall be plugged with a good insulator, so as to prevent leakage of mercury. The specimen shall be set up and the test carried out in a manner similar to that specified in (*c*).

(*e*) *Conditions of test.*

The resistance shall be measured, at the end of each minute, over a period of ten minutes' electrification, at a potential difference of 500 volts. The resistivity shall be expressed in megohms for a centimetre cube after one, two, and ten minutes' electrification respectively.

The materials shall be tested in accordance with



NOTE.—The specimen must be held down in the mercury by a weight of about 50 gm.

FIG. 4.—Arrangement of Specimen in Fig. 3 set up for Resistivity and Surface Resistivity Tests.

conditions (*a*), (*d*), (*e*), (*f*), (*g*), and (*h*) given in Clause 2 of this Specification.

4. *Surface Resistivity (Surface Leakage).*

(*a*) *Moulded materials.*

The surface resistivity of moulded material shall be tested on a specimen of the shape and dimensions shown in Fig. 1, and set up generally in the manner indicated in Fig. 2. The specimen shall rest on three pins fixed into the lower steel electrode, the top of the pins being 2 mm below the upper edge of the steel electrode. The internal diameter of the steel electrode shall be 98 mm, and the specimen shall be so placed that it does not touch the internal surface. The depth of the electrode in the inner cup shall be approximately 2 mm; and the groove in the top edge of the specimen shall be filled with mercury. The electrodes shall be connected to the battery and galvanometer as shown in Fig. 5, so as to measure the surface resistance between the mercury in the groove in the top edge of the specimen and the lower electrode.

For temperatures not exceeding 100° C. mercury electrodes shall be used. For higher temperatures suitable fusible metal electrodes shall be used, if necessary, according to the temperature.

(*b*) *Sheet materials.*

The surface resistivity of sheet material shall be tested when possible on a specimen of the shape and dimensions shown in Fig. 1. When it is impracticable to obtain a specimen 20 mm thick the overall thickness may be reduced to a minimum of 12 mm, the thickness of the base being 5 mm in every case. The other dimensions shall be in accordance with Fig. 1. The specimen shall be set up with suitable electrodes as in (*a*), generally in the manner indicated in Fig. 2, the connections to the battery and galvanometer being as shown in Fig. 5.

All the surfaces of the specimen shall be machined smooth, but not polished. The specimen shall be tested with the surfaces as left by the tool, unless special circumstances render it necessary for them to be finished in a particular manner in service.

(*c*) *Rods.*

The surface resistivity of a rod shall be tested by boring out the rod so as to form a deep cup, and turning

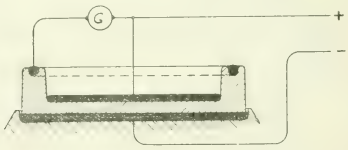


FIG. 5.—Electrical Connections to Specimen in Fig. 1 set up for Surface Resistivity Test.

the outside surface. The dimensions shall be as shown in Fig. 3.

The specimen shall be set up for testing with suitable electrodes as in (*a*), generally in the manner indicated in Fig. 4.

The outside surface of the specimen shall be machined smooth, but not polished. The specimen shall be tested with the surface as left by the tool, unless special circumstances render it necessary for the surface to be finished in a particular manner in service.

(*d*) *Tubes.*

For testing the surface resistivity of a tube, one end shall be plugged with a good insulator, so as to prevent leakage of mercury. The specimen shall be set up and the test carried out in a manner similar to that specified in (*c*).

(*e*) *Conditions of test.*

The surface resistance shall be measured, after one minute's electrification, at a potential difference of

500 volts, and the surface resistivity shall be expressed in megohms for a centimetre square.

The materials shall be tested in accordance with conditions (*a*), (*b*), (*c*), (*e*), (*f*), and (*g*) given in Clause 2 of this Specification.

5. *Electric Strength* (*Puncture Strength*).

The electric strength of material in moulded or sheet form shall be tested on a specimen of the shape and dimensions shown in Fig. 6.

The test shall be carried out by applying an alternating potential difference between a spherical and a flat surface. Contact with the flat surface of the specimen shall be obtained with a flat disc, 40 mm diameter, which shall make good contact with the surface of the specimen. The middle of the disc shall be opposite the thinnest part of the specimen. Contact with the spherical surface shall be obtained by the use of shredded lead, mercury-tin amalgam, or other suitable material, pressed into intimate contact with the surface of the specimen. Similar materials shall be used for the flat surface if required by its nature to obtain effective contact. The frequency of the alternating

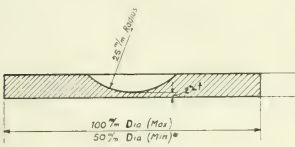


FIG. 6.—Specimen for Electric Strength Test.

* For materials of low electric strength which will not flash over.

† For a material having a very high electric strength this dimension (2 mm) must be decreased so that the specimen will puncture at a potential difference not exceeding 80 000 volts. For coarse materials this dimension may be increased to a maximum of 5 mm by arrangement.

potential difference shall be about 50 periods per second, the wave-form being approximately sine shaped.

The potential difference shall be applied without shock, and shall be increased at such a rate that the specimen is punctured in about 20 seconds. The potential difference shall be expressed in volts per millimetre (R.M.S.) computed from the following formula *:—

$$X = \frac{V}{T f}$$

where X = breakdown volts per mm (electric strength),
V = volts required to puncture specimen,
T = minimum thickness of specimen in mm,
f = function depending on the thickness T.

With one electrode consisting of a sphere 25 mm radius and the other a disc as specified, the values of f for various thicknesses of specimen are as given in the following table :—

Minimum Thickness of Specimen T, mm	Approximate Value of f
0·5	1·01
1·0	1·03
2·0	1·05
3·0	1·08
4·0	1·11
5·0	1·14

If the electric strength of the material is so high that the specimen cannot be punctured in air the test may be carried out under oil.

The materials shall be tested in accordance with conditions (*a*), (*d*), (*e*), (*f*), (*g*), and (*h*), given in Clause 2 of this Specification.

* This formula is adopted from " A Treatise on the Theory of Alternating Currents," vol. i, by Dr. A. Russell.

Mechanical Tests.

6. *Toughness* (*Absence of Brittleness*).

Toughness shall be proved by an Impact Test carried out with a machine of the pendulum type, at a temperature from 15° C. to 20° C.

The form and dimensions of the specimen for moulded material shall be as shown in Fig. 7. The notch shall be moulded in.

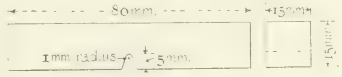


FIG. 7.—Moulded Specimen for Impact Test.

The form and dimensions of the specimen for sheet or rod material shall be as shown in Fig. 8. The notch

FIG. 8.—Specimen (machined from Sheet or Rod) for Impact Test.

shall take the form of a drilled hole 1 mm radius opened out to the side of the specimen by a saw cut. When it is impracticable to obtain sheet 15 mm thick, the

width of the specimen may be reduced to a minimum of 12 mm, the other dimensions remaining as in Fig. 8.

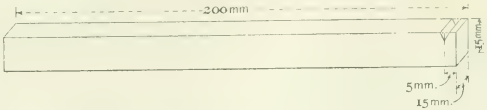


Fig. 9.—Specimen for Plastic Yield with Temperature Test and Cross-breaking Strength Test, machined from Sheet or Rod, or Moulded.

As certain materials may have different values for toughness, depending on the direction of the blow with reference to the surface of the sheet, whenever possible impact tests shall be carried out with the blow delivered in directions parallel to, and at right angles to, respectively, the surface of the sheet. The velocity of the pendulum at impact shall be between 180 and 220 cm per second. The minimum energy required to break the specimen shall be ascertained, and shall be expressed in kg cm per sq. cm of the broken surface. The energy remaining in the pendulum after breaking the specimen shall not exceed 25 per cent of the total blow in any test, and shall be less when practicable.

Note.—Whilst the specimen should be as nearly as possible of rectangular section, the bedding of the pendulum is improved by giving a slight curvature to the vertical edge of the supports, such that the point of contact with the specimen will be on the centre line of the latter. Small adjustments of the energy of blow may be made by altering the velocity within the limits given above. Larger alterations have to be effected by changing the mass of the pendulum.

7. *Plastic Yield with Temperature (Rigidness).*

The plastic yield with temperature of material in moulded, sheet, or rod form, shall be tested on a specimen of the shape and dimensions shown in Fig. 9. When it is impracticable to obtain sheet 15 mm thick the width may be reduced to 12 mm, the other dimensions remaining as in Fig. 9.

Fig. 10 shows the method of applying the test. The clearance between the sides of the specimen and the stirrup shall not exceed 0·5 mm.

The specimen shall be fixed in the clamps without loading and a measurement made of the height of the unsupported end above the datum point. The specimen shall be heated for two hours at a temperature 5 deg. C. above grade temperature, and a load then applied. For a specimen 15 mm wide the load shall be 450 grammes, and for other widths 30 grammes per mm. The specimen shall be maintained thus for 20 hours, at the end of which period, and whilst still

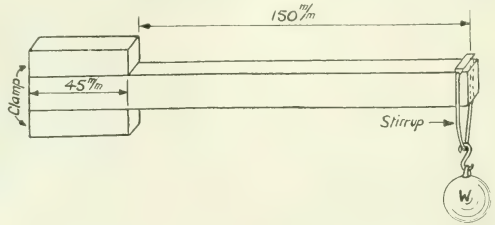


Fig. 10.—Arrangement of Specimen in Fig. 9 set up for Plastic Yield with Temperature Test and Cross-breaking Strength Test.

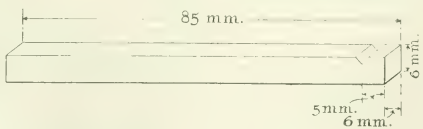


Fig. 11.—Alternative Smaller Specimen for Plastic Yield with Temperature Test and Cross-breaking Strength Test, machined from Sheet or Rod.

hot, the height shall be re-measured. With the weight on, the unsupported end shall not have yielded more than 10 mm.

Another specimen shall then be set up and tested in the same manner, except that the test shall be carried out at grade temperature, at which temperature the yield shall not exceed 2·5 mm.

When it is impracticable to obtain a specimen in accordance with the dimensions shown in Fig. 9, the smaller alternative specimen shown in Fig. 11 may be used. The smaller specimen shall be set up as shown in Fig. 12 and tested as described above, except that the load applied shall be 72 grammes.

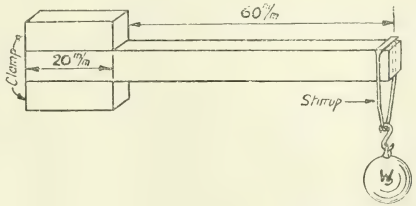


FIG. 12.—Arrangement of Specimen in Fig. 11 set up for Plastic Yield with Temperature Test and Cross-breaking Strength Test.

8. *Cross-breaking Strength.*

(*a*) *Cross-breaking strength at normal temperature.*

The material shall be tested at a temperature from 15° C. to 20° C.

The specimen shall be of the shape and dimensions shown in Fig. 9, and shall be set up for testing generally in the manner indicated in Fig. 10. The load shall be increased gradually at the rate of 10 kilogrammes per minute until the specimen breaks.

The cross-breaking strength at normal temperature shall be expressed in terms of the constant k in the following formula :—

$$W = \frac{kBD^2}{L}$$

where B, D and L are in centimetres and W in kilogrammes, B being the breadth of the specimen, D the depth, and L the distance between the edge of the clamp and centre of the notch.

(*b*) *Cross-breaking strength at grade temperature.*

The specimen employed for the Plastic Yield Test at grade temperature shall be tested as follows :—

With the specimen set up for test under Clause 7, and immediately after the height of the unsupported end has been re-measured as described in Clause 7, and whilst the specimen is still hot, the load shall be gradually increased at the rate of 10 kilogrammes per minute until the specimen breaks. If the unsupported end yields 20 mm before fracture occurs the specimen shall be deemed to have failed, and the value of the load causing this deflection shall be taken in computing the cross-breaking strength.

The cross-breaking strength at grade temperature shall be computed in the same manner as in (*a*) above.

When it is impracticable to obtain a specimen in accordance with the dimensions shown in Fig. 9, the smaller alternative specimen shown in Fig. 11 may be used. The smaller specimen shall be set up generally in the manner indicated in Fig. 12 and tested as described above, except that the specimen shall be deemed to have failed when the unsupported end yields 8 mm before fracture occurs.

9. *Crushing.*

The ability of the material to resist crushing shall be proved at a temperature from 15° C. to 20° C. in a testing machine on a specimen moulded or machined to the shape and dimensions shown in Fig. 13. The end faces of the specimen shall be truly square,

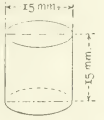


FIG. 13.—Specimen for Crushing Test.

plane and parallel, being rubbed down on fine emery paper if necessary, with due precaution against rounding.

If a specimen of the size shown in Fig. 13 cannot be cut from the material available, a smaller cylinder, geometrically similar, may be used, but not less than 10 mm long and 10 mm diameter.

An initial load of about 100 kilogrammes per sq. cm shall be applied and the initial length of the specimen read under this load, in order to eliminate the compression due to bedding on the ends. The load ultimately registered shall include this initial load.

A series of loads shall then be applied to the specimen and the yield for each load shall be determined after one minute and ten minutes respectively.

The yield shall be measured by the change of distance between the two compressing surfaces by means of two direct-reading gauges, one on each side of the specimen, the mean of the two being taken, or, alternatively, the two gauges may be combined so as to give a single mean reading. A magnification of not less than 100 should be used.

For the 15 mm specimen, the minimum load that gives a yield of 0·5 mm, when computed from the following formula, shall be deemed to be the crushing load :—

$$\text{Yield} = y + \frac{0{\cdot}25\,y}{y'}$$

where y and y' are the yields in millimetres at ten minutes and one minute respectively. When the dimensions of the specimen are less than 15 mm the permissible yield shall be reduced in proportion.

10. *Ageing.*

To test the ability of a material to retain its mechanical characteristics after exposure to high temperature, specimens of the form and dimensions shown in Fig. 9 shall be maintained for a prolonged period at the grade temperature of the material.

To ascertain the effect of the heat treatment, specimens shall be tested at intervals by being allowed to cool to a temperature between 15° C. and 20° C., and then tested for cross-breaking strength as described in Clause 8 (*a*), and the results obtained compared with those obtained before the heat treatment.

Miscellaneous.

11. *Density.*

When density (mass per unit volume) is an important factor for ascertaining the suitability of a material, it shall be determined at 20° C. and shall be expressed in grammes per cubic cm.

Note.—The density (mass per unit volume) of a solid heavier than, and unaffected by, water can be accurately determined by the following method :—

The weight (M_1) of a stoppered weighing bottle filled at 20° C. with freshly boiled distilled water is first determined. An accurately weighed sample of the material, of weight M_2, is then introduced into the partially emptied bottle, and any air bubbles removed by placing the unstoppered bottle in a vessel, which is then exhausted with an air-pump. The bottle is then filled at 20° C. with air-free distilled water, re-stoppered, and weighed (M_3).

The weight of the water displaced by the solid is given by the following expression :—

$$\text{Weight of water displaced} = M_1 + M_2 - M_3,$$

and, assuming D as the density of water at 20° C. (i.e. 0·9982), the density of the material * is given by the following formula :—

$$\text{Density of material} = \frac{M_2}{M_1 + M_2 - M_3} \times D$$

12. *Water Absorption.*

A specimen 5 cm square and 5 mm thick shall be dried in a desiccator at a temperature from 15° C. to 20° C. until it ceases to lose weight, and then weighed with the usual precautions. It shall then be immersed in water at room temperature for 24 hours. The specimen shall be taken from the water and, after removing the surface moisture by wiping, shall be weighed again. The weight shall be taken to the nearest milligramme in each case. The percentage absorption of water shall be computed on the original weight of the specimen.

Tooling Characteristics.

The tooling characteristics of the materials shall be determined by the tests specified in Clauses 13 and 14.

13. *Tool Wear.*

Tool wear shall be determined by making four equal cuts having a total length of 1 600 ft. (helical). The tool wear shall be measured at the end of each cut of 400 ft. (helical).

For the purpose of grading the material, the tool

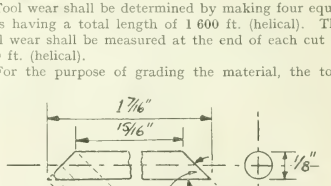


Fig. 14.—Method of Measurement of Tool Wear.

A = Length of face of new tool.
B = Length of face of worn tool.
A minus B = Tool wear.

wear shall be ascertained by measuring the length of the face of the tool on the axis where the maximum wear has taken place (see Fig. 14), and shall be expressed in mils.†

(*a*) *Specimen.*

When practicable a specimen 14 inches long, 2 inches external diameter and 1 inch internal diameter shall

* It is unnecessary to take account of the density of air in this calculation.

† The following are suitable methods of measuring the tool wear :—

(i) The use of a reading microscope, the tool being viewed in the direction of maximum wear and measurement being made of the depth of the worn surface at right angles to the top face of the tool.

(ii) The use of a micrometer direct, or measuring from a suitable fixed stop on the holder, thus avoiding removing the tool.

be employed. If a specimen of these dimensions is not obtainable another form of specimen may be used, provided a total length of cut of 1 600 ft. can be made on the specimen.

(*b*) *Tool.*

The cut shall be made with the following tool :—

Form	See Fig. 15.
Material	Silver steel.
Diameter	$\frac{1}{8}$ inch.
Tool angle	45°.
Front clearance	45°.
Top rake	0°.
Temper	Glass-hard in clean cold water, and left with a good cutting edge.

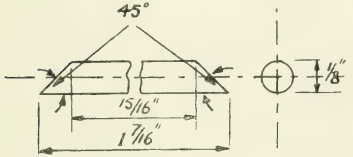


FIG. 15.—Form of Tool for Tool Wear Test.

The tool shall be finished on a fine oilstone, using a jig to ensure obtaining the specified angle and accurate shape.

The angle θ at which the tool is set to the axis of the specimen shall be adjusted so that the wear is substantially at the end of the tool (see Fig. 16).

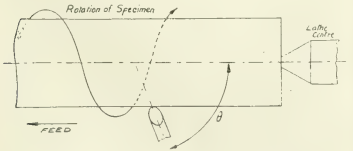


FIG. 16.—Setting of Tool for Tool Wear Test.

The tool shall be set accurately centrally so that the plane of its upper face contains the axis of rotation of the specimen.*

(*c*) *Conditions.*

The surface of the specimen shall be made parallel before each cut, so as to remove the taper produced by the previous tool wear. After each cut, the depth of the fresh cut shall be reduced at the start by an amount corresponding to the radial wear of the tool, so as to obtain the equivalent of one continuous cut 1 600 ft. long.

The cut shall be made under the following conditions :—

Cutting speed	= 100 ± 5 ft. per minute.
Depth of cut	= 0·020 ± 0·002 inch.
Revolutions per inch of feed	= 64.
Temperature of the specimen	= 20° C. ± 2·5° C.

All materials should be tested dry. If, however, it be desired to obtain results with lubricant, the same test shall be employed, and a definite lubricant shall be specified by the manufacturer of the material for the purpose of the test. When reporting on a material tested with lubricant, full particulars of its composition and the rate of flow of the lubricant during the test shall be stated.

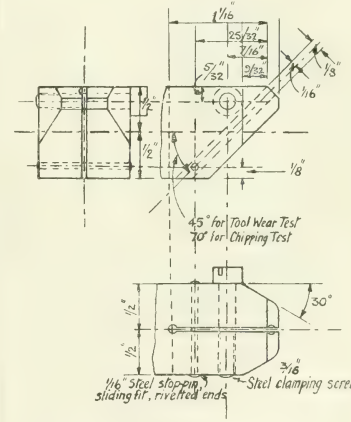


FIG. 17.—Form of Tool Holder for Tool Wear and Chipping Tests.

14. *Chipping.*

(*a*) *Specimen.*

For the purpose of grading the material with respect to chipping, a taper cut shall be made on a rod 5 inches long and not less than 1 inch, or more than 2 inches, diameter. The specimen shall be turned parallel before the taper cut is made.

The chipping constant for the material shall be the depth of the cut in inches multiplied by the diameter of the specimen in inches, at the point where chipping commences.

* A suitable form of tool holder is shown in Fig. 17.

(*b*) *Tool.*

The taper cut shall be made with the following tool : —

Form of tool	See Fig. 18.
Material	Silver steel.
Diameter	$\frac{1}{8}$ inch.
Tool angle	70°.
Front clearance	20°.
Top rake	0°.
Temper	Glass-hard in clean cold water and left with a good cutting edge.

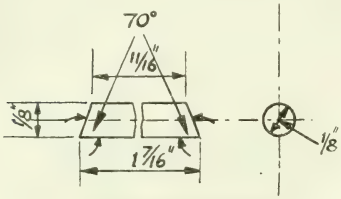


Fig. 18.—Form of Tool for Chipping Test.

The tool shall be finished on a fine oilstone, using a jig to ensure obtaining the specified angle and accurate shape.

The tool shall be set at an angle of 75° to the axis of the specimen.*

The tool shall be set accurately centrally, so that the plane of its upper face contains the axis of rotation of the specimen. A newly sharpened tool shall be used for each specimen. Shoulder chipping shall be taken as the criterion (see Fig. 19); and the taper cut shall be continued until chipping is visible to the naked eye.

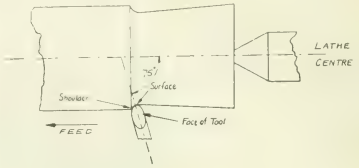


Fig. 19.—Setting of Tool for Chipping Test.

(*c*) *Conditions.*

The taper cut shall be made under the conditions given below, the specimen being kept under observation for chipping :—

Revolutions per minute	$= 100 \pm 2$.
Revolutions per inch of feed	$= 48$.
Taper	$= 1$ in 50.
Temperature of the specimen	$= 20°$ C. $\pm 2{\cdot}5°$ C.

All materials should be tested dry. If, however, it be desired to obtain results with lubricant, the same test shall be employed, and a definite lubricant shall be specified by the manufacturer of the material for the purpose of the test. When reporting on a material tested with lubricant, full particulars of its composition, and the rate of flow of the lubricant during the test, shall be stated.

* A suitable form of tool holder is shown in Fig. 17.

DISCUSSION ON

"THE 'CYC-ARC' PROCESS OF AUTOMATIC ELECTRIC WELDING."*

North-Western Centre, at Manchester, 24 January, 1922.

Mr. L. Miller: Anyone who has had any experience of electric welding will have often wished that he could eliminate the human element; the "Cyc-Arc" apparatus takes the process of welding out of the hands of the operator and ensures that each similar joint is made under exactly similar conditions of time, current density and arc length. I regard the method of timing the operation as admirable and have found it very trustworthy in operation. With regard to the type of generator described in the paper, I think the authors will agree that I have demonstrated to them that quite as good results can be obtained at much less cost with a simple compound-wound generator with reversed series winding. The use of this type of generator enables the resistances to be done away with and therefore simplifies the apparatus considerably. At the same time very great advantages are obtained when very heavy currents are required.

Mr. J. Anderson: The most likely use of the "Cyc-Arc" welding set is the welding of steel studs to steel. That is much more necessary and usual than the welding of brass or copper studs to steel. I doubt very much whether the authors will get old-fashioned mechanical engineers to look with any degree of favour upon this system for the welding of studs. Among mechanical engineers generally there is a great objection to the use of electricity in making mechanical connections. We ourselves in our business have had this objection to overcome in order to get electric welding to the state in which it is at present.

Mr. A. B. Field: In connection with the welding of dissimilar metals I should like to refer to the work done by L. W. Chubb in the United States in about 1912. He was able to obtain a ductile weld between aluminium and copper. He also welded materials of very dissimilar melting points, e.g. tin and aluminium, copper and platinum, tin and platinum, etc. His method consisted in the very rapid discharge of a condenser through the point of contact of the two metals, combined with a simultaneous mechanical blow. He has since used electromagnetically stored energy in place of the electrostatically stored energy, for heavier welds. The method has been used to some extent in the United States, but does not appear to be very well known over here. British Patent 15 479 of 1912 bears upon the earlier method.

Mr. H. Purslow: I am particularly interested in Fig. 11. Although the studs welded on to the mild steel angle ring which is cast into the box flange withstood the test satisfactorily, I do not consider this to be a commercial proposition, as the extra work involved in this application would cost more than the ordinary drilling and tapping, and in my opinion would not be as good a job. I should like to know to what degree of success mild steel studs have been welded directly on to cast-iron flanges, without, of course, the costly angle ring, and what tests they were subjected to. If steel studs can be welded directly on to cast iron there is a good future for the "Cyc-Arc" system in this sphere alone, when one considers the large amount of engine, pump and turbine castings at present drilled and tapped for studs. I should also like to know if it is possible to weld brass or yellow-metal studs directly on to cast iron.

Mr. A. B. Mallinson: I should like to know whether the authors have found this process of welding to give satisfactory results with aluminium or aluminium alloys on to steel or brass plates.

Mr. W. T. Robson: In connection with the bonding of railway lines, one of the difficulties of this system will be the amount of apparatus which appears to be necessary. If a railway line is going to be electrified the service has to be kept going all the time, and it is difficult to see how a petrol engine, generator, and this welding apparatus can be brought alongside, particularly on a viaduct. That is one of the difficulties we meet with in advocating the electric bonding of railway metals. I should like to know exactly, if possible, how much space is occupied by the complete apparatus for such a purpose.

Mr. L. H. A. Carr: Does dirt affect the welding operation, i.e. must the surface be reasonably clean, or is the presence of rust or paint immaterial?

Mr. H. S. Binns: In dealing with rail bonds, the authors show thimbles welded to the rails, the actual bond being riveted or soldered to these thimbles. Is this method used owing to the possibility of electrical connection, apart from the bond, between the rails; or to some difficulty in securing a satisfactory weld when a body heavy in comparison with a stud, such as a long copper bond, is to be welded; or to a difficulty in welding copper to steel? The first possibility does not necessarily hold good in practice, as apart from the fish-plates, which are readily removable, there is seldom direct contact between rail-ends, and, where the bonding of a third rail is concerned, this can be readily taken care of.

Mr. W. A. Wales: With reference to the question raised by Mr. Binns, there would be no difficulty in making the first weld, but afterwards there would be a short-circuit through the weld which had already been made, and no arc could be struck. In order to use bonds which are welded to the rails, these would have to be fixed in two halves and a mechanical connection made with bolts. These would be apt to work loose and would be no better than the ordinary bonds now used.

Messrs. L. J. Steele and **H. Martin** (*in reply*): While we fully appreciate the interest which Mr. Miller and the Metropolitan-Vickers Electrical Co. have taken in the design of special direct-current motor-generators in

* Paper by Messrs. L. J. Steele and H. Martin (see pages 136 and 236).

connection with the "Cyc-Arc" apparatus, we are not convinced that equally good results can be obtained at a much less cost with a simple compound-wound generator with reversed series winding as with the special machines described in the paper. We think, however, that a machine of the type proposed by Mr. Miller, including some of the features of the Brush Company's design, and fitted with a flywheel, if only for the purpose of reducing the size and cost of the motor, would be an almost ideal arrangement to meet "Cyc-Arc" requirements.

In reply to Mr. Anderson, we were rather surprised at the prejudice against the use of brass studs in this country, but as their use has now been accepted, possibly partly on account of certain obvious advantages, for ship work, we see no reason why it should not be extended to other branches of engineering. We agree that ultimately there will be a much wider field in the welding of steel to steel, but it is interesting to note that probably the "Cyc-Arc" process will first come into general use for the welding of relatively expensive alloy steels to mild steel in various forms of tool manufacture, before being adopted for mild-steel stud welding. A very useful application in this direction which has recently been experimented upon with highly successful results is in the welding of high-speed steel twist-drills to mild-steel taper or parallel shanks. This application is bound to effect great economies in the manufacture of such drills.

We have heard of the impact method of welding described by Mr. Field, and have seen some of the results obtained with it; these are both interesting and remarkable. One great objection to the general commercial application of this method of welding, however, appears to be the great size, weight and cost of either form of energy-storing charging and discharging device, and we think that the method of welding in question is in no way comparable with our process for convenience and cheapness in adaptation and operation, as far as general engineering requirements are concerned.

In reply to Mr. Purslow, as the result of advice and information obtained in other directions, we do not agree that the extra work involved in the proposed method of welding studs to cast-iron flanges by our process would cost more than the ordinary drilling and tapping, and, furthermore, Mr. Purslow seems to ignore the advantages which would accrue in some classes of work, from the fact that the stud is firmly welded, and therefore fixed at one end, with no possibility of working loose. We do not consider that steel studs welded to cast iron will give appreciably better results than brass studs, and we are not prepared to recommend such forms of "Cyc-Arc" welding. Satisfactory welds can, however, be made to cast steel of certain qualities.

In reply to Mr. Mallinson, we have so far had little opportunity to experiment in the welding of aluminium, but we have made very satisfactory welds of aluminium-alloy studs on to aluminium plate. We also feel sure that the "Cyc-Arc" process will be found capable of effecting satisfactory welds of aluminium or aluminium alloys to steel or brass plates.

We fully recognize the difficulty in railway-line electric welding quoted by Mr. Robson. This difficulty could, however, be overcome by welding short brass or copper studs to the rails before they are actually laid, more particularly in the case of viaducts, and then completing the bond by methods similar to those now in use and described in the London discussion. In considering the welding of the bonds or other accessories to the rails when laid in position, we would point out that this work can be done very rapidly, and that, if proper preparations were made, there are few viaducts on which the rail bonding could not be done by means of our process within 2 or 3 hours. The whole portable "Cyc-Arc" welding equipment, including the small petrol-engine-driven flywheel generator, should weigh well under 1 ton, and could easily be accommodated upon a small railway trolley having a platform 8 ft. long × 6 ft. wide.

In reply to Mr. Carr, the cleanliness of the surface upon which "Cyc-Arc" welding is done certainly does affect the quality of the resulting weld, more particularly in the case of small studs. Although the presence of rust or paint does not necessarily prevent satisfactory welds being made, the results with clean plate are so much better and more uniform that it is well worth the trouble of cleaning beforehand. This cleaning can, however, be done quite quickly and easily, and is in no sense elaborate.

In reply to Mr. Binns, one reason for our bonding proposals, to which he refers, as compared with the direct welding of the bonds to the rails, is that up to the present "Cyc-Arc" welds of copper to steel have not been obtained with a mechanical strength approaching that of equivalent welds of brass to steel. In addition, however, while it is recognized that apart from the removal of fish-plates, etc., one bond might be welded direct to adjacent rail-ends, we believe that it is the universal practice to fit two such bonds, in which case there would be an obvious difficulty in the welding of the second one.

Although the remarks of Mr. Wales refer mainly to the questions raised by Mr. Binns, we would point out that even if the bonds were welded to the rails in halves which had to be mechanically connected together, it is very much better to make, by mechanical means, electrically satisfactory connections between copper or brass bonds than between the bonds and the steel rails.

North Midland Centre, at Leeds, 14 February, 1922.

Mr. W. E. Burnand: I was rather impressed by the short period of time taken to weld a light tube, i.e. 0·2 second, but the system used for welding light articles such as spectacle frames is very much quicker. In this case there are two parts to be welded, one attached to a sort of typewriter bar with a spring-actuated hinge across a condenser. These parts are then simply sprung together and welded, the actual welding taking about 0·001 second. There is some slight resemblance to the system demonstrated by the

authors, in that the parts to be welded are impelled together rapidly, but the analogy ceases there. Another system was described in about 1920 by Mr. D. F. Miner of the American Westinghouse Company. This system has the particular feature that a reactance is used which stores electromagnetic energy in a big core with a nearly closed magnetic circuit. This is charged up comparatively slowly, and discharged in a fraction of a second. That piece of apparatus takes the place of the flywheel motor-generator which the authors utilize, and enables a very heavy discharge to take place in a very small time without requiring a large current from the supply. Some figures are given in *Machinery* of 4th October, 1920. An oscillogram taken during a weld between copper and steel rods $\frac{3}{4}$ inch in diameter indicated a peak of current of 2 600 amperes, an arc of 30 volts, a maximum power of 60 kW, an expenditure of energy of 0·00077 kWh, and the welding time as 0·094 second. That corresponds in parts fairly closely to some of the figures obtained by the authors, but the process is somewhat quicker. Can the authors say of what dimensions and weight this core would have to be to store the amount of energy required for $\frac{1}{2}$-inch stock? With regard to the pillar drill shown on the slide, I should like to suggest that it might be advisable to combine the push button with the handle. Have the authors experimented with the welding of "Stellite" to steel for machine tools?

Mr. S. E. Hall: When the experimental weld was made, the arc seemed to be quenched before the main circuit was opened. Is there not a considerable rise in current during that period, because it seemed to be an appreciable proportion of the total welding time?

Mr. E. Balmford: What is the effect on the weld if the surfaces to be welded are covered with grease, paint or scale, etc., especially if, in the case of the latter, it is fairly deeply embedded? Have the surfaces to be carefully cleaned? Also, do slight variations in the compositions of the metals to be welded affect the weld, and, if so, in what manner and to what extent? Finally, is it necessary for the brass studs to have a definite composition?

Mr. A. Hall: I wish to draw attention to another welding process which was developed by Dr. S. Z. de Ferranti 19 years ago and which was carried on for a number of years quite successfully. The problem differed somewhat from that which the authors had to face. We were welding steel blades on to turbine discs and drums, and accuracy of setting, as well as strength and certainty, was essential. We developed what is known as resistance welding and used in our machines automatic timing and breaking of the electric circuit much in the manner described by the authors. The time of welding varied from 0·4 second to 6 seconds. The blades taking the latter time were of about $\frac{1}{2}$ sq. in. section. To make the welding possible, the section of the drum had to be reduced slightly. In the case of a blade $\frac{1}{8}$ inch wide, three grooves $\frac{3}{64}$ inch wide and $\frac{1}{8}$ inch deep were formed in the rim where the row of blades had to be welded. Small blades were welded at the rate of 6 per minute, the time being determined by the rate at which a man could move the head of the machine to and fro. The welding itself took only 0·4 second. We welded chiefly blades of steel, steel alloys and steel covered with nickel, but could quite successfully weld bronze or gun-metal. Many millions of such blades were welded, and are still running in the various turbines so fitted.

Mr. S. D. Jones: The authors' process seems to be most successful in connection with the welding of dissimilar metals. Would not this method be useful for attaching studs to boilers to withstand high pressure?

Messrs. L. J. Steele and **Martin** (*in reply*): The authors have heard of the method of welding described by Mr. Burnand, but some of the facts which he mentioned are both new and interesting. Reference was made to similar methods in the Birmingham discussion and, as stated there, we consider such methods to be in no way comparable with the "Cyc-Arc" process for cheapness in operation and ease in adaptation as far as general engineering requirements are concerned. As stated in the paper, the total energy required to weld a $\frac{1}{2}$-inch stud by the "Cyc-Arc" process need not exceed 12·5 watt-hours, and this information will probably enable Mr. Burnand to determine the dimensions and weight of the core of the electromagnetic storage device to which he refers. With reference to the suggestion, with which we quite agree, that with the pillar-drill attachment of the welding tool it might be advisable to combine the push button with the handle, our lantern slide showed merely the portable-type tool adapted and fitted to a post drill. If this adaptation, however, came into general use, certain modifications such as the one suggested would be made. We have not yet had an opportunity of attempting to weld "Stellite" to mild steel.

In reply to Mr. Hall, there is certainly a rise in current in the main welding circuit between the time of the completion of the weld by the replacement of the stud against the plate and the actual opening of the main circuit contactor. The time for which this rise takes place is, however, well under 0·5 second, and can be still further reduced if desired. The rise in current referred to is not a serious matter in making small welds with substantial regulating resistance in circuit, but it certainly may be troublesome in dealing with large welds taking heavy currents. It is proposed to meet this difficulty, in such work, by the use of specially designed generators with reversed series field windings, so that the rise in current would be relatively small.

In reply to Mr. Balmford, the effect on the weld when grease, paint, scale, etc., are present on the surfaces to be welded has been dealt with in previous discussions. Although "Cyc-Arc" welding can be accomplished even if the surfaces to be welded are dirty, rough cleaning and preparation of the surfaces before making the weld is always fully justified by the more uniform and better welds obtained. Variations in the composition of the metals to be welded certainly affect the welds, mainly in the direction of their mechanical strength. As would naturally be expected in welding to mild steel, certain alloys give much better results than others. For instance, good quality naval brass in which there is practically no lead gives excellent results when welded to mild steel. A relatively small percentage of lead in the brass, however, produces a very

disproportionate decrease in the mechanical strength of the weld. It is therefore advisable, if not actually necessary, for the brass studs to have a definite composition, which fortunately is not expensive and is easily manufactured and obtained.

We are greatly interested in the resistance method of welding turbine blades to which Mr. Hall refers, and to which reference was also made in the Birmingham discussion; but we would again observe that there is no similarity whatever between the "Cyc-Arc" process and any method of resistance welding, though it is interesting to note that automatic timing and control have been applied to the last-mentioned method.

In reply to Mr. Jones, we feel sure that when the "Cyc-Arc" process becomes sufficiently well known and understood it will be applied in boiler work.

PROCEEDINGS OF THE INSTITUTION.

676TH ORDINARY MEETING (JOINT MEETING WITH THE INSTITUTION OF HEATING AND VENTILATING ENGINEERS), 19 JANUARY, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting of the 12th January, 1922, were taken as read, and were confirmed and signed.

Messrs. A. H. Allen and H. M. Sayers were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Members.

Eldridge, Edwin John
Emanueli, Luigi.
Hunt, James Alfred.
Jewett, Frank Baldwin.
Nash, Reginald Percy.
Roberts, John.
Schuil, Johannes.
Williams, Edward John.
Wood, Arthur Henry.
Youngs, Charles John.

Associate Members.

Armstrong, Robert Edward.
Attrill, Percy Francis.
Baker, Alfred Ernest.
Bartlett, Arnold William.
Betts, Douglas.
Borver, Walter Frederick.
Brookes, Ralph Caldecott.
Brooksbank, Norman.
Butchart, Peter Steven.
Cleaver, John.
Coates, George Alfred.
Contell, Fernando.
Cooke, Robert Radcliffe.
Crocker, James Russell.
Crooks, Edward Joseph.
Davies, David Hugh.
Dunthorne, Henry Ralph J.
Dyer, Albert Victor.
Evans, Athol Gerald.
Freeborn, Charles Fernandez.
Galloway, Joseph.
Gill, Richard.
Grant, Harold Walter.
Green, Herbert William.
Grierson, John.
Hall, Frederick Martin.
Hartridge, Howard William.
Higman, Henry Philip L.
Hird, Maurice.
Holmes, Oliver, B.Sc.
Hooper, Ernest Joseph.
Jeynes, Mark.
Johnson, Gilbert King.
Ker, Dudley Wellwood.
Lidgey, Frederick John.
Liley, Edward L.
Lloyd, Charles, Lieut. R.E.
Lloyd, Stephen Walter.
McCandless, John.
Marr, Herbert Richard.
Milne, George Yeoman.
Murgatroyd, Frederick.
Nielsen, Otto Frederick S.
Odam, John Harold.
O'Neill, James Wooldridge.
Patterson, Walter John.
Pearson, Stephen Oswald, B.Sc. (Eng.).
Robinson, Isaac Richard.
Sanders, George.
Scutt, William Duke.
Shelton, Arthur.
Smerdon, Thomas.
Smout, Donald Trentham.
Taylor, Roland Hutton.
Thomas, Eiman Oliver P.
Todman, James Claud.
Trowman, Prof. Harry Frederick, M.A.
Turner, Frederick Fuller.
Wade, Cyril Selwyn.
Walls, Robert Young.
Waters, William Alexander.
Webster, Henry Shepherd.
White, Charles Frank H., B.Sc. (Eng.).
Wilkinson, William Henry.

Graduates.

Adams, Ernest Hirons.
Bhandari, Prakash Chandra.
Butterfield, Edwin.
Chakravarti, Sudhakar.
Christophersen, Leif Lie.
Clifford, Leonard Percy.
Coleman, John Frederick.
Donnelly, Kieran.
Entwistle, Joseph.
Evans, David Beynon.
Francis, Henry Heeman.
Galloway, William Charles G.
Gordon, Alan Ramsay.
Hall, Richard Charles.
Hall, William.
Harrower, William.
Hawkins, Ernest James.
Hayes, Arthur Purchase.
Henshaw, Lewis.
Hopkin, David William.
Hovanesian, William.
Johnston-Steel, Charles Henry.
Keillar, Alan Bernard.
King, Alfred George.
King, Herbert Harvey.
Longbottom, Claude Muller.
Lovell, George Charles R.F.
McClean, Thomas.
McGoff, John Clement.
McKowan, Francis Leslie.
Mason, Percy Herbert.
Misra, Munna Lal.
Moffat, John.
Moore, George Edward.
North, Sydney Ernest.
Parsons, Lionel Uniacke.
Peet, Claud George.
Robson, William Bruce.
Sampson, Charles Victor.
Sarsfield, Leslie Gerald H., B.Sc.
Sclater, Frank Arthur, O.B.E., M.C., B.A.
Shaw, Wilfrid Leonard.
Wade, Cecil Forrester N.
Jesselton.
Wakefield, Paul Stuart.
Webbe, Horace Frank.
Whitehouse, Harry Edward, B.A.
Yusuf, Mohammed Luthfullah S.

Students.

Allan, James Thomson.
Addenbrooke, Jack Hibell.
Adey, John Edward.
Agrawal, Lakshman Swarup.
Akehurst, Herbert Farrant.
Allen, Cecil Ernest.
Ambady, Govindan Kwtty.
Anderson, Forrest S.
Andrewes, Humfrey.
Armstrong, Reginald Basil.
Arnold, Alan Hugh M.
Ashley, Percy Gilman.
Austin, Charles Valentine.

Students—continued.

Baker, Leslie Frederick M.
Banerji, Shyamananda.
Banks, Edward Bernard.
Bannister, Reginald Harry.
Barnes, Leslie Thomas.
Barrett, Harry Eden.
Barrington, Ralph.
Barry, Charles.
Batty, Harry.
Baxter, George.
Bealing, Ernest.
Beck, William Llewellyn.
Beckwith, Frank.
Beed, James Colin.
Bellis, John Edgar.
Bennett, Leslie.
Bennett, Robert Francis.
Berry, Jack Milton H.
Bird, Maurice.
Bissett, Alexander Reid.
Blackler, Clarence William.
Bracewell, John Hougton.
Brady, Albert Francis.
Bramley, Eric Charles.
Brennan, Hugh.
Britton, Frederick Thomas.
Brown, Charles Alexander C.
Brown, Derrick Charles.
Brown, Walter John, B.Sc.
Buchanan, William McEwen, Jun.
Burton, William Charles L.
Bushell, Herbert John.
Byrne, Edward Joseph.
Caldicott, Richard Arthur H.
Cameron, Gilbert Victor.
Carroll, James Arthur.
Carter, Alan.
Cassal, Charles Victor.
Channon, Derrick Harry W.
Chase-Currier, Humphrey Anthony.
Churchward, Ernest Walker W.
Clark, John Eric.
Clarke, Stephen Herbert.
Clucas, Reginald Marwel.
Coates, Albert William.
Coles, Carl Featherstone.
Combes, Frank Roy, B.E.
Condron, Lovis Thomas.
Copland, William Oranmere.
Corkett, John Frederick L.
Corkill, William Alfred.
Coulehan, John Clement.
Cribb, Ernest Hatfield.
Crutchett, Charles Alfred.
Cuddeford, Donald Vernon.
Curtis, William Cyril.
Dakin, Eric McEwan.
Dargavel, Frank William.
de Miranda, Ignacio Frazao V.
Devereux, Reginald William.
Dick, Alastair William.
Ditchfield, Gilbert.
Douglass, William Bramley.
Dowty, Murray John.
Duarte, Adolphus Swithin.
Duerden, Tom.
Duncan, Charles.
Duncan, James Thomson.
Eastick, Lawrence Edward K.
Egerton, Frank Pownall.
Elton, Edward.
Emerson, Samuel James.
Erskine, Steuart Edward.
Evans, Alan Wainwright.
Evans, Arthur Vicary.
Evans, Percy.
Fenech, George.
Fieldhouse, John Nelson.
Fielding, Harry.
Firth, Norman.
Flesher, Richard Gordon.
Ford, Robert James.
Foster, Alan Dunlop.
Frost, Albert Harry.
Gadkary, Sadashiv Atmaram, B.E.
Galloway, James.
Gates, Bertram Alfred.
Gee, Frank Watson.
Gibbons, Wilfred John.
Gibson, John Walter.
Glover, Edward.
Golding, Edward William.
Goldthorpe, Sam Leslie.
Goodchild, Frank Douglas.
Gowdridge, Francis.
Gravett, Ronald Morford.
Gray, Cyril George.
Grimwood, Charles James.
Groves, George Robert.
Hague, Hector Donald.
Hall, Harold Stuart M.
Hall, Harry.
Hallam, Tom Eric.
Hardern, Harold Wilfred.
Harle, John Douglas.
Harris, John Karslake.
Harrison, Thomas Reginald P.
Harrison, Walter James.
Hassan, Sheikh Manzur.
Hawkesley, Edgar.
Haydock, William James.
Hazare, Gajanan Balvant.
Helliwell, Joseph Brook.
Heyes, Clifford.
Hill, Arnold Parker.
Hill, George.
Hill, Horace Leslie.
Hogg, Duncan Bardsley.
Holding, George Harold.
Hornby, Wilfred.
Howard, John Kemble.
Howell, Eric Ernest.
Howitt, Dudley Herbert.
Howse, Henry Arthur G.
Hughes, William Howard.
Humphreys, Charles Fogden.
Hutchinson, Fenwick.
Irwin, Charles King.
Jones, Gilbert Ellis.
Jones, Leslie Newton.
Jones, Sydney Baden.
Kelso, Alexander.
Kemp, Maurice Pattison.
Kenyon, John.
Kindon, Alec Edward.
Kipp, Edward D.
Laing, Walter Barron.
Langford, Stanley.
Langlois, Edwin Mauger.
Lash, Robert Francis.
Latimer, Dennis.
Latimer, Walter Herbert.
Leben, Henry.
Leghorn, Douglas Sutherland.
Lewis, Frank Melville.
Lewis, William Kenneth.
Lewis, Owen.
Lindley, Gerald
Lishman, Reginald Chandler.
Lord, George.
Lord, Wilfrid Austin.
Loustalan, Jules Joseph V.
Low, George.
Lowe, Alexander McLeay.
Lupton, Tom Reginald.
Macara, Kenneth Graham F.
Macarthur, John Alexander.
Macdonald, Hector Atherton.
Macfarlane, James Ernest.
Mackenzie, Keith Stewart.
McKnight, William Alexander.
McLaren, James Thoburn.
McLean, George Osborne.
MacLeod, Donald Brabazon.
McNeilage, Alexander Blackwood.
Maidman, Francis William.
Malet-Veale, Cecil John E.
Marshall, Harold Frank.
Martinez, Guillermo.
Matthews, William Knowles.
Mavor, Albert Bernard.
Maycock, Alan.
Meek, John.
Metcalf, Alfred Whitley.
Michael, Harold Verney.
Miller, John Leonard.
Mitchell, Denys Lindley.
Mitton, Aubrey Roy D.
Mohring, Albert John G.
Moorhouse, Ben.
Morgan, Frederick William.
Morgan, Hedley Edmund.
Morphy, Tudor Edward R.
Mortlock, Joseph Ronald.
Moss, Leslie Clive A.
Mukherji, Debkiuker.
Murray, Henry Percy.
Nagle, Ronald Francis.
Naidu, S. R. Madhavakrishna.
Nicholls, George Henry C.
Northcott, Martin Floyd.
Nunn, William Archibald.
Ockerse, Roebert Gerrit.
O'Connor, Francis George.
O'Connor, Thomas Francis.
O'Dea, William.
Oliver, George William.
Owen, Clive William.
Owen, John Ewart.
Palmer, Wilson.
Parkin, Geoffrey William.
Pearce, William Harold.
Pennal, Herbert William.
Penney, Stephen William.
Perkins, James William.
Phillips, Edward John.
Pinder, Fred.
Platt, Eric.
Povedano, Albert Richard.
Preston, Charles Ernest.
Provan, Ernest Alexander.
Ramberg, Eric Axel.
Randall, Roland.
Reith, Ewart Laurence.
Renton, Alexander.
Renwick, William.
Ridding, John Willett.
Ritchie, David Anderson.
Roberts, Frederick Arthur.
Roberts, Thomas Dew.
Rook, Eric Barnard
Roscoe, William.
Rosser, John Ellis.
Rowbotham, John Lincoln.
Rowe, Bertram John.
Sandels, Harry George.

Students—continued.

Sayers, Donald Phillpott.
Scott, Eric Walter N.
Semper, Edwin Seymour.
Sharp, Leslie Cyril.
Sharples, Harry.
Shepherd, George Raymond.
Sheppard, Maurice William.
Short, Oswald Williams.
Silcocks, Leonard William J.
Simpson, William Arthur.
Slade, William Charles.
Smith, Frederick Stretton.
Smith, William Monro.
Snell, Maurice Saxon.
Southworth, Albert.
Speller, Alfred Gardner.
Stallard, Arthur Julian.
Stirling, James, Jun.
Stirling, Wallace.
Stoyanovitch, Dragolyul.
Sur, Provash Chandra.
Sutcliffe, Albert.
Tait, William McDiarmid.
Taylor, Arthur Russell.
Taylor, Eric Openshaw.
Taylor, James Edward
Taylor, Joseph.
Thomas, Frank.
Thomas, Thomas Baden.
Thomas, William Neam.
Thompson, John Crighton.
Tidy, Sydney, B.Sc. (Eng.).
Tingle, Howard Grantley.
Traynier, Maurice Anthony.
Treloar, Noel Gordon.
Turner, Victor Robert.
Turrell, Francis Henry.
Tutton, Philip Aubrey.
Tyler, Stanley Suett.
Uden, Hector Francis.
Uglow, John Curtice.
Underwood, Ronald Herbert.
Varley, Robert.
Veale, Frank Leslie.
Vidler, William George.
Wadham, Giles Anthony.
Walker, John Dobbie.
Wall, George.
Wallis, Preston Ralph.
Walmsley, William Herbert G.
Walters, Albert Edward P.
Walton, Ronald Webber.
Ward, Percival Alfred.
Warren, Wilfred Ernest.
Warrior, Nates Krishna.
Washington, Albert Bryan, B.Sc. (Eng.).
Wells, Stanley Chappell.
West, Ronald.
White, Hubert Robert C.
Whitehead, Thomas Eric.
Wigan, Edmund Ramsay.
Wild, Eric Egbert.
Willats, Ernest Howard.
Williams, Frank.
Wilson, Charles Alfred.
Wilson, Peter Murray.
Woodall, Raymond Harcourt.
Wright, John Dingwall.
Wyborn, Edward John.
Youatt, Brian Dinsdale.
Young, Adam.
Yovanovitch, Miloche V.

TRANSFERS.

Associate Member to Member.

Anderson, John.
Anson, Bernard Oglie.
Atkinson, James William.
Baxendale, Thomas.
Brown, Harry Percy, M.B.E.
Brown, Henry, O.B.E., Major R.E. (T).
Cash, Henry James.
Crawshaw, Edmund.
Day, William.
Feltham, John Barrett.
Gibbon, Andrew Owen.
Gill, Archibald Joseph, B.Sc. (Eng.).
Harper, Edgar.
Hart, Arthur Benjamin.
Hedley, John.
Higgs, Walter Frank.
Ivison, Edgar Joseph.
Miles, Henry James.
O'dell, George Frederick, B.Sc. (Eng.).
Page, Edgar John.
Pedler, Ivor Augustus D.
Rayner, Edgar Sturely.
Record, John Westmoreland.
Rolfe, William John.
Saunders, Frank Ernest.

Associate Member to Member—continued.

Shorrocks, Frederick Walter.
Tabor, Henry John H.
Tandy, Frank.
Trench, Arthur Henry C., Major, C.I.E., R.E.
Watson-Weatherburn, Sydney Weatherburn.
Weaver, Richard Albert.
Wilson, Rowland.
Wright, Archibald.

Associate to Member.

Andrews, Leslie Henry.

Graduate to Associate Member.

Bown, Frederick James.
Clinch, William Norman C.
Cobbold, Geoffrey Wyndham N., B.A.
Davis, Vernon Lionel F.
Griffith, John Eaton.
Griffiths, Henry Rae.
Johnson, Eric Maurice, M.Sc.
Knight, Frederick James.
Lang, Frank James C.
Vandermin, Conrad.
Viall, Hugh Roger.

Student to Associate Member.

Biles, Reginald William.
Brocklehurst, Harold John S.
Clifton, John Punnett.
de Murga, Henry.
Houghton, Thomas Evans.
Kerr, William Wallace.

Associate to Associate Member.

Hudson, Noel, Lt.-Col., D.S.O.

Student to Graduate.

Ablett, Clifford Beresford.
Ballard, Clarence Mansfield.
Bedford, John Thornton.
Davison, Russell Hawes.
Deacon, Edward Charles.
Dhar, Ashok Kumar.
Doxat-Pratt, Maurice.
Dutta, Sisir Coomar, M.Sc.
Franks, Henry Bertram S.
Ibeson, Willie.
Judson, Ralph.
Keen, Walter Whitworth.
Lakey, Eric Harold, B.Sc.
Lewis, Gwilym.
Lewis, Hubert John.
Lloyd, William Francis.
McDermott, Harold Richard.
Mackay, William John.
McLean, Ian Kennedy.
Messer, William Gustave.
Montague, William McAdam T.
Postlethwaite, Henry Victor.
Rogers, Arthur Harry E.
Wright, Charles Henry W., B.Sc.

The President announced that arrangements had been made for members to dine together at the Engineers' Club after the Ordinary Meeting to be held on the 2nd February.

A discussion took place on "The Utilization of Waste Heat from Electrical Generating Stations" (see p. 273), with the following introductory papers :—

"Utilization of Exhaust Steam from Electric Generating Stations, and Coal Economy," by Mr. C. I. Haden, Past President of the Institution of Heating and Ventilating Engineers (see page 265); and "The Utilization of Waste Heat from Electrical Generating Stations," by Mr. F. H. Whysall, Member (see page 271).

The meeting terminated at 7.55 p.m.

AN INVESTIGATION OF TRANSMITTING AERIAL RESISTANCES.

By T. L. Eckersley, B.A., B.Sc.

(*Paper received* 31*st October, and read before the* Wireless Section, 7*th December,* 1921.)

Summary.

This paper, as its title implies, deals with the subject of the resistance of transmitting aerials.

It describes an attempt which has been made to reduce to a minimum the energy losses in the neighbourhood of such aerials, which are known to be very inefficient.

It is shown that favourable results are obtained by interposing a screen of wires between the aerial and earth, and using this screen as a counterpoise earth instead of using the usual buried earth.

The losses in such a system are analysed and it is shown that a large fraction of the earth losses are eliminated when such a screen is used.

Formulæ are devised for predetermining the resistance of screened aerials, in terms of the conductivity of the earth and the surface dielectric loss.

Such aerials have the drawback that the wires of the screen itself may form an oscillating system, and under certain conditions oscillations are set up in this system which waste energy. Methods of dealing with and eliminating these losses are discussed.

Finally, the method of screening is compared with Alexanderson's multiple-earth system, and it is concluded that a combination of the two methods should give the best results.

Introduction.

The experiments described in this paper were undertaken at the suggestion of Captain Round, who for some years past had realized their importance but had not had the opportunity of carrying them out. The sanction of the Marconi Wireless Telegraph Co. was obtained for the necessary heavy expenditure involved in these experiments.

Except for the pioneer work of Alexanderson with multiple, earthed aerials, not much progress had, until then, been made in the improvement of the efficiencies of wireless circuits and aerials, chiefly on account of the lack of accurate measuring appliances for tracing the various transformations of energy which take place in these circuits. The importance of the subject, especially with regard to long-wave transmitting aerials of large size, which are known to be very inefficient, had long been recognized, but it was not until the recent development of continuous-wave valve circuits that the necessity for high-efficiency aerials became prominent or the means for investigation were developed.

In the case of long-wave transmitting aerials for high-power stations, the situation as regards efficiency is acute. It is well known to wireless engineers that long waves are necessary to transmit over long distances, but the useful radiation—which is proportional to the square of the aerial height divided by the square of the wave-length—becomes insignificant compared with the other losses when the wave-length is sufficiently long.

The reason for this is obvious when we reflect that there is a practical limit to the height of an aerial, say about 800 ft., so that for wave-lengths of over 10 000 metres the radiation resistance cannot be greater than one ohm, and with longer waves is reduced in proportion to the inverse square of the wave-length.

At 20 000 metres the radiation resistance will be less than $\frac{1}{2}$ ohm and the total resistance of the aerial and earth will probably be of the order of 2 ohms, so that only about 10 per cent of the energy delivered to the aerial is radiated, i.e. is employed in useful work. The only ways of increasing this efficiency are:

(1) To increase the height, at the expense of very costly towers, which are in fact at present unpractical above 800 ft.; and
(2) To reduce the dead losses in the surrounding earth and wires so that they shall be small compared with the radiated energy.

In this paper an account is given of the result obtained by attacking the problem from the latter point of view.

It is well known that a large part of the energy delivered to the aerial sinks into the neighbouring ground and is not recovered. It was therefore with the idea of screening the earth from the electromagnetic effects of the aerial current that the experiments were carried out (at Broomfield in July 1919).

For this purpose an inverted L-type aerial was used, and a screen of wires parallel to the horizontal part of the aerial and insulated from the ground was employed in the manner of a balancing capacity.

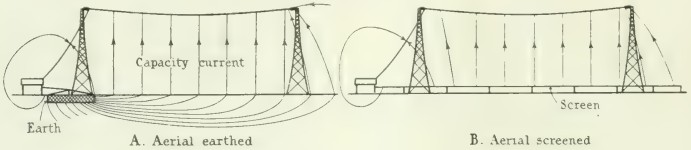
Of course, there is no novelty in the use of such a set of wires in this manner, since many aerials, notably the Lodge aerial, have been of this form; but the lower wires of these aerials have been generally considered to act merely as capacities to earth and their true function as earth screens has not been realized.

In order to get some sort of theoretical basis for calculating the screening, the electric force due to the charges on the aerial at any instant was assumed to be in a steady or quasi-stationary state. This assumed distribution of electric force is nearly the same as that calculated by Maxwell for a grid of wire placed in a uniform electrostatic field (see Fig. 4B).

It may be observed that in the inverted L-type of aerial the current flows in a circuit consisting of the vertical part of the aerial, the horizontal part and the condenser formed by the aerial capacity and the earth. The function of the screen is to intercept

the lines of force from the aerial to earth and to carry the return current on the screen wires rather than the earth (see Fig. 1).

According to Maxwell's formula, an earthed screen with wires 1 ft. apart and 2 ft. 6 in. above the ground will carry 80 per cent of the current, leaving 20 per cent in the ground, and if the same screen is insulated there will be less than $\frac{1}{10\,000}$ per cent R.M.S. earth current.



A. Aerial earthed B. Aerial screened

FIG. 1.—Screening of earth-return currents.

The screen was accordingly designed on this basis, and consisted of 64 wires at 1 ft. spacing, 200 ft. long, supported on wooden posts and triatics at a height of 2 ft. 6 in. from the ground. It covered all the space below the aerial and extended in all directions an amount at least equal to the height of the aerial (i.e. 15 ft.) beyond the latter.

The quasi-stationary theory, though correct as far as it goes, is admittedly incomplete. The following experiment, however, confirms the general accuracy of these ideas. When the screen was placed as in Fig. 2

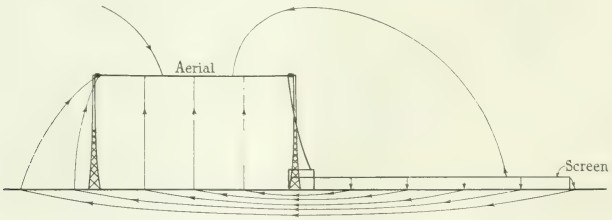


FIG. 2.—Earth-return currents.

so that it did not shield the aerial, the resistance was much larger than when the screen was placed directly below the horizontal part of the aerial. The actual figures were of the order of 5 ohms in the former case and less than 1 ohm in the latter case.

The reason for this difference is obvious enough when it is remembered that the earth is unshielded below the aerial and that the path of the earth-return currents is of great length.

THEORY OF SCREENED AERIAL.

It may be desirable at this stage to give, in rough form, a more complete theory of the aerial, so that the experimental observations may be more easily interpreted when these are described.

The electric field due to the charges and the varying currents in the aerial can be divided into two portions, which play essentially different parts in the theory of the screen, and should be clearly distinguished at the outset.

The electric forces can be put in the form :—

$$X = -\frac{\partial F}{c\,\partial t} - \frac{\partial \psi}{\partial x}$$
$$Y = -\frac{\partial G}{c\,\partial t} - \frac{\partial \psi}{\partial y}$$
$$Z = -\frac{\partial H}{c\,\partial t} - \frac{\partial \psi}{\partial z}$$

where ψ is a retarded potential function $\int \left[\frac{e}{r}\right]_{t=-r/c}$ which, at distances from the aerial short compared with the wave-length, is practically indistinguishable from the ordinary potential of the charges on the aerial.

F, G, H are the x, y, z components of Maxwell's vector potential, which are derived from the charge.

Thus $F = \int \left[\frac{u}{r}\right]_{t=-r/c}$.

The part of the field due to the vector potential which is parallel to the horizontal part of the aerial is the one to which it is desired to draw attention. The physical difference of the two parts is fairly obvious. Naturally the part due to ψ is the electric force due to the potential of the charges, and the parts due to the variation of F, G, H are the induced E.M.F.'s due to the varying currents.

The quasi-stationary state which was originally assumed only takes account of the forces due to ψ, and neglects the horizontal electric forces which are readily seen to be caused by the variation of the currents in the screen and aerial wires. The effect of these horizontal electric forces is to produce eddy currents in the earth, which add to the dead losses in the aerial.

Another way of looking at the subject, perhaps more familiar to wireless engineers, is from the point of view of radiation. An aerial of the form shown in Fig. 3

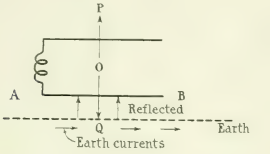


FIG. 3.

will radiate energy in the directions OP, OQ, if isolated in space. If the lower limb AB of the aerial is placed just above the earth, the aerial will still radiate in the direction OQ, but the energy radiated will be partly reflected and partly absorbed at the surface of the earth; in fact, the currents induced in the earth are a measure of the reaction of the latter against the radiation in this direction. These are what have been previously referred to as the eddy currents and are responsible for the loss.

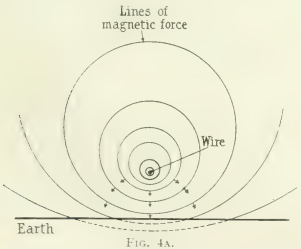


FIG. 4A.

In calculating the losses due to this cause it has been found most convenient to revert to the original point of view and to consider the currents induced in the earth by those in the screen and aerial wires.

Consider a section of an aerial and screen, in which for simplicity both are single wires. If the height of the upper wire is sufficiently great, its effect may be neglected in comparison with that of the lower wire. The varying current in this latter wire will produce lines of magnetic flux, closed loops expanding and contracting, which cut the earth and produce eddy currents parallel to the wire, with consequent losses (see Fig. 4A).

From whatever point of view we envisage the action of the screened aerial, whether that of the electric force, magnetic force, or the radiation, we arrive at the same results, which may be summarized in the following salient points:—

(1) The losses in the earth are produced by the agency of the horizontal electric force which, in its turn, is produced by the differential action of the horizontal currents in the aerial and screen.

(2) Since there is necessarily a downward radiation from any aerial with horizontal wires, the loss in the earth cannot be completely eliminated except when the conductivity of the earth is perfect, or when there is a perfect reflector between the screen and earth.

(3) The leakage electric force perpendicular to the surface of the earth and calculated on the quasi-stationary theory will contribute to any loss due to the presence of bad dielectrics at the surface of the earth.

It is easy to realize that the quasi-stationary theory can give no information with regard to the losses in the earth; for the distribution of electric force is, on this theory, the same as that due to the static charges. The electric force at the surface of the earth is therefore everywhere perpendicular to it, and the flow of energy according to Poynting's theory must be everywhere parallel to the surface of the earth, so there can be no loss in the earth, since no energy flows into it.

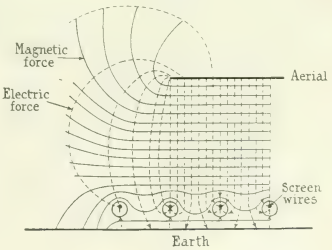


FIG. 4B.

It is through the action of the horizontal force, which is neglected on the former theory, that energy flows into the earth and is lost.

RESULTS.

When interpreted in the light of this rough theory, the facts first brought to light in the experiment referred to show themselves amenable to explanation.

Perhaps the most striking of these, at any rate from a practical point of view, is the reduction of the resistance of the screened aerial as compared with that of the earthed aerial. These results are shown on curves in Fig. 5, and it can be seen at a glance that there is

a fourfold reduction of resistance on all wave-lengths ranging from the natural wave-length of the aerial to about four times this wave-length.

The significance of this result will be perhaps more easily perceived when it is realized that the power required to produce a given current in the aerial, and hence a given range, is reduced four-fold when using the screened aerial. Or again, assuming that a definite amount of power is supplied, the screened aerial is equivalent to an earthed aerial of double the height. (This is, of course, only true when the earthed aerial is relatively inefficient and the radiated power is only a small fraction of the total power supplied to the aerial.) These results were sufficiently encouraging to warrant a very careful examination of the resistance of the screened aerial in order to determine which of the remaining losses could be reduced or entirely removed.

The form of the resistance-wavelength curves shown in Fig. 5 is typical of all aerials whether earthed or screened. The curve is obtained in the following

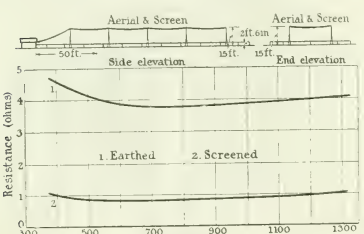


Fig. 5.—Resistance of L aerial.

manner. The aerial is loaded with a low-resistance inductance to bring its wave-length to that at which the resistance is required. The resistance of this system is then measured by a method described later in the paper. The resistance of the inductance alone is then measured by tuning it up to this by an air condenser of negligible loss. The true aerial resistance, which is the difference of these, is plotted against the wave-length.

Resistance Measurements.

The subject of high-frequency resistance measurement merits a word to itself. It is a comparatively new development in wireless research and has only been perfected since the advent of steady continuous-wave oscillators. The method employed throughout these experiments is the "added resistance" method in which the reduction of current produced by a heterodyne circuit on inserting a known resistance is noted.

The only novelty is in the measurement of the current. To be strictly accurate the current is not measured and it is only a voltage-drop across the loading inductance, proportional to it, that is observed.

Since only relative and not absolute values of the current are involved in the formula, it is quite correct to use the voltage-drop in place of the current.

The advantage of this method * is that the measuring device does not introduce any extra resistance into the oscillatory circuit; also it is in most cases more sensitive than the current-measuring method, since it requires less energy to produce a readable voltage than a readable current on a thermo-ammeter. The method should be accurate to about 2 per cent if due precautions are taken. The most important of these is to shield the measured circuit from the direct electrostatic induction of the heterodyne. In practice about 5 per cent accuracy is claimed.

The resistance which is measured by this method is the quantity which when multiplied by the square of the R.M.S. current at the point where the added resistance is inserted, gives the mean rate of dissipation of energy in that circuit. This specification of the current employed is important in the case of aerials, where the current varies from point to point.

Experimental Results.

We may return, after this digression, to the discussion of the actual experimental results. If the resistance is plotted against wave-lengths a typical curve of the form shown in Fig. 5 is obtained. For short waves the resistance is relatively high. It reaches a minimum between $1\frac{1}{2}$ and 3 times the natural wave-length of the aerial, and then rises again on longer wave-lengths. For very large ratios of λ to λ_0, the resistance is very nearly proportional to λ, and in some cases may increase even more rapidly than the first power of λ.

Now, the contributions to the aerial resistance we have already recognized are:—

(1) The radiation resistance: $k \times 1\,580\,\frac{h^2}{\lambda^2}$.

(2) The wire resistance: $\alpha\,\frac{1}{(\lambda)^{\frac{1}{2}}}$.

(3) The eddy-current resistance: $\alpha\,\frac{1}{(\lambda)^{\frac{1}{2}}}$ nearly.

All these contributions to the resistance vary inversely as some power of the wave-length, so that the total resistance due to all these causes should decrease with increasing λ on all wave-lengths.

Dielectric Loss.

The rise in resistance exhibited on long waves is, therefore, due to some cause other than those already quoted. Now this cause has been shown by John M. Miller † to be the presence of bad dielectrics in the electric field of the aerial, for he was able to reduce this increase to small proportions by removing as far as possible all suspicious dielectrics from the field of the aerial. This conclusion has been abundantly confirmed by the author's own experiments both on screened and unscreened aerials, and there seems to be little doubt of its truth.

* *Radio Review*, 1921, vol. 2, p. 303.

† *Proceedings of the Institute of Radio Engineers*, 1919, vol. 7, p. 299.

The resistance due to this cause is, as near as can be measured, directly proportional to the wave-length. It is usual when discussing dielectric loss to consider the aerial as forming a condenser; to assume that it has a constant power factor; and hence to deduce that the resistance of a constant-capacity circuit should be proportional to the wave-length.* This may appeal to the engineer who is familiar with power factors, but it seems a little arbitrary to the physicist, who might be inclined to ask: "Why should the power factor remain constant?" It seems to me, therefore, to be preferable to deduce the proportionality of R and λ from more fundamental assumptions.

It can be shown that the result follows from the assumption that a certain fraction of the energy stored in the condenser formed by the aerial and earth screen is lost per period of oscillation.†

Perhaps the simple example of a parallel-plate condenser will make this clear. The energy stored per unit volume is $(K/8\pi)X^2$, where K is the specific inductive capacity, and X the electric force. Let us suppose that a fraction, g, of this is lost per period,

then $\dfrac{gKX^2}{8\pi}$ = energy wasted per period, and

$\dfrac{gnKX^2}{8\pi}$ = energy wasted per second per cm³

(where n = frequency).

The total energy wasted in the condenser is

$$\frac{ngKX^2}{8\pi}\text{(volume)} = \frac{ngKX^2Ad}{8\pi}$$

where A is the area of the plates, and d their distance apart.

$$\text{Loss} = \frac{ng}{2}\cdot\frac{AKX}{4\pi}dX$$

Now, $\dfrac{KXA}{4\pi} = Q$, the charge on the condenser, and $dX = V$, the potential difference of the plates, so that

$$\text{loss} = \frac{ng}{2}QV$$

If $Q = Q_0 \sin pt$; $p = 2\pi n$; $I_0 = pQ_0$; n = frequency,

$$\text{loss} = \frac{ngI_0V_0}{2p} = \frac{g}{4\pi}\frac{I_0}{Cp}(CpV_0)$$

Now $CpV_0 = I_0$;

hence $$\text{loss} = \frac{g}{4\pi}\cdot\frac{I_0^2}{Cp} = R_d\frac{I_0^2}{2}$$

therefore $$R_d = \frac{g}{2\pi Cp} = \frac{g\lambda}{(2\pi)^2Cv}$$

where R_d is the equivalent dielectric-loss series resistance.

* For loss $= IV\cos\phi$ nearly, where I = current, V = voltage, and ϕ = constant power factor. Now, $V = I/Cp$, $\therefore$ loss $= (I^2/Cp)\cos\phi = (\phi/2\pi)I^2\lambda$, i.e. $R = \phi\lambda/2\pi Cv$, is proportional to λ if ϕ and C are constant.

† This argument can be generalized for any form of condenser and distribution of dielectrics.

We see that when g, the fraction of the energy stored per period which is lost, and C, the capacity of the system, remain constant, the resistance is proportional to the wave-length.

This assumption is very much more fundamental than that of a "constant power factor."

The abundant evidence that R_d varies in proportion to the wave-length confirms this simple relation between the energy wasted and that stored.

Leakage Loss.

In a few cases the resistance increased even at a faster rate than the first power of the wave-length, but in such cases the too rapid rise of R is almost always traced to the effect of leakage. This will readily be seen to introduce a term proportional to the square of the wave-length, for if R be the resistance of leak across the condenser (supposed so large that only a fraction of the current is taken by R), then the loss due to this cause is V^2/R, that is

$$\frac{I^2}{p^2C^2R} = \frac{I^2\lambda^2}{(2\pi)^2C^2Rv^2}$$

it is proportional to λ^2.

Bearing these facts in mind we see that the resistance can be analysed into four parts:

(*a*) Radiation resistance: $\alpha\dfrac{1}{(\lambda)^2}$.

(*b*) Eddy-current and wire resistance: $\alpha\dfrac{1}{(\lambda)^{\frac{1}{2}}}$ nearly.

(*c*) Dielectric loss resistance: $\alpha\lambda$.

(*d*) Leakage resistance: $\alpha\lambda^2$.

Analysis of Losses.

Given a resistance-wavelength curve it is merely a matter of mathematics to fit a curve of the form: $\dfrac{A}{(\lambda)^2} + \dfrac{B}{(\lambda)^{\frac{1}{2}}} + C\lambda + D\lambda^2$ and so find the magnitudes of the various contributions to the total loss.

Experiments with Screen.

In the case of the screened aerial, an elevation of which is given in Fig. 6, the study of the origin of the losses was further facilitated by making experiments with various arrangements of the earth screen wires. Not only did these experiments serve the practical purpose of setting a limit to the number of screen wires necessary in a given case to reduce the resistance to within a given fraction of its lower limit, but they serve the more useful purpose of clearly indicating the origin and nature of the losses. The 64 wires of the screen, each 1 ft. from its neighbour and 2 ft. 6 in. above the ground, were brought each to a separate terminal so that any arrangement of the wires could be used.

Two sets of experiments were carried out, in each of which the number of wires in the screen was varied.

In the first set, A, the wires were progressively

thinned out, leaving the span over which they spread practically the same in every case, i.e. 63 ft. The spacing between the wires therefore varied inversely as the number of wires.

In the second set, B, the wires used were left at 1 ft. spacing so that the open span or breadth of the screen decreased with the number of wires, being in being the eddy-current resistance and the second the dielectric-loss resistance, both at $\lambda = 1\,000$ m.

In the curves A of Fig. 9 the actual calculated resistance of the wires has been subtracted, leaving only the resistance over and above this, which we have assumed is due to the eddy currents induced in the earth.

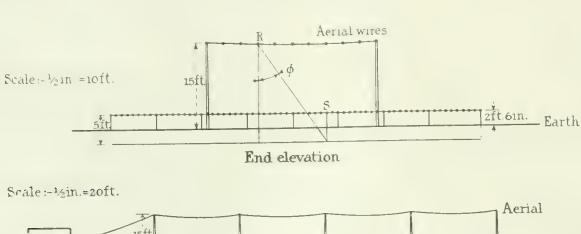


Fig. 6.—Inverted L aerial and screen.

fact equal to $N - 1$, where N is the number of wires used.

The results of the experiments A and B are exhibited in the curves of Figs. 8A and 8B which show the dead loss (i.e. total R – radiation R) resistance plotted against the wave-length. The figure against each curve in Fig. 8A represents the number of wires in the screen for which the curve is taken. The curves in

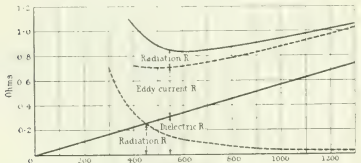


Fig. 7.—Analysis of losses on L aerial and screen.

Fig. 8B explain themselves. These curves can be analysed into two parts

$$(a)\ \alpha \frac{1}{(\lambda)^{\frac{1}{2}}}; \quad (b)\ a\lambda$$

The part (a) is due to the eddy currents and wire resistances. The part (b) is dielectric loss. There was apparently no leakage loss in this particular set of experiments.

We thus obtain separately the variation of the eddy currents and dielectric-loss resistances with the number of wires in the screen at any given wave-length. This will be seen in the curves of Figs. 9 and 10, the first

In the first place, this curve bears no resemblance to the curve of Fig. 11 which shows the variation of the root-mean-square leakage field (calculated on

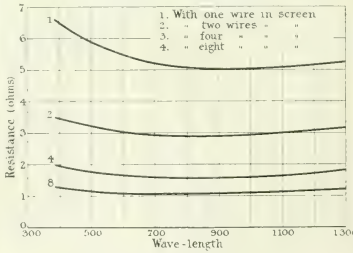


Fig. 8A.—Dead-loss resistance.

the quasi-stationary theory) with the number of wires in the earth screen. In the second place, since when the wires are few the resistance is practically inversely proportional to the number of wires in the screen (which are in parallel, be it observed), it is natural to suppose that a certain definite resistance is associated with each wire. When the wires are sufficiently close the resistance tends to a certain lower limit and does not decrease in the inverse proportion of the number of wires; in fact, practically no decrease is occasioned by increasing the number of wires from 8 to 64, as the curve shows, although this would mean an eight-fold reduction if the resistance still varied inversely as the number of wires when these are sufficiently close together.

The reason for all this is fairly obvious when we recall the rough theory of the aerial given in the earlier part of the paper. It was pointed out that the alternating currents in the screen and aerial wires would produce eddy currents in the earth, which would absorb energy and add to the resistance of the aerial. For

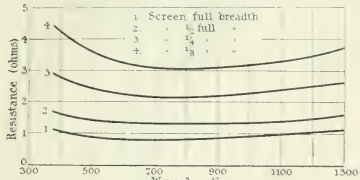


FIG. 8B.—Total resistance.
Span varied; spacing constant.

this reason, an isolated wire will have associated with it an extra resistance R per unit length, which will be a function of the height of the wire above the ground, the resistivity of the earth, and the frequency of the oscillations.

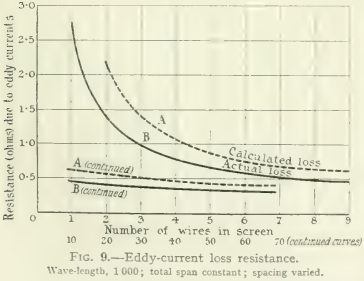


FIG. 9.—Eddy-current loss resistance.
Wave-length, 1 000; total span constant; spacing varied.

The author has succeeded, after much laborious work, in calculating what this extra resistance should be in terms of the three quantities just given.

At sufficiently high frequencies, when the quantity $h\left(\frac{4\pi\mu}{\rho}\right)^{\frac{1}{2}}$ is large compared with unity, the resistance per centimetre is

$$R_0 = \frac{2}{h}\left(\frac{\rho\mu}{4\pi}\right)^{\frac{1}{2}} \times 10^{-9} \text{ ohms},$$

where h is in centimetres and ρ is in C.G.S. electromagnetic units.

At lower frequencies and heights above the ground the formula is more complicated, but the resistance may be derived from the above expression by multiplying by a factor K, which lies between 0 and 1 and can be evaluated from a certain definite integral.

The curve in Fig. 12 shows the variation of K with the frequency for wires at the heights of 1 m and 5 m respectively for a resistivity $\rho = 2 \times 10^{12}$ C.G.S. units. The abscissæ and ordinates used are the logarithms of the frequency and R_0 in the two cases respectively, since this form of scale gives a more complete form of representation.

Consider now two wires A and B, so far apart compared with their height above the ground that the

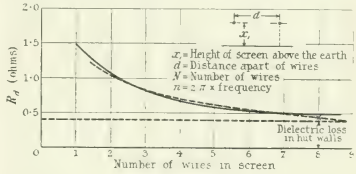

R_H (ohms)
x = Height of screen above the earth
d = Distance apart of wires
N = Number of wires
n = 2π × frequency
Dielectric loss in hut walls
Number of wires in screen

FIG. 10.—Dielectric loss.
Wave-length, 1 000; total span constant; spacing of wires varied.

eddy currents produced by them do not appreciably overlap, that is, so that the currents produced by A in the neighbourhood of B are negligible, and vice versa. The resistance of the wires A and B in parallel will be half that of either. But this is not the case if A and B are close together. The energy loss in the ground then contains a term due to the overlapping currents and it is obviously greater than the sum of

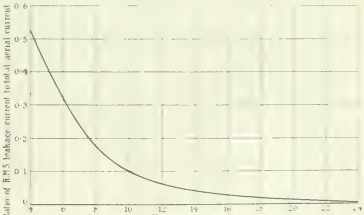


FIG. 11.

the losses in A and B separately. If the current I is divided between A and B equally, the loss is

$$\tfrac{1}{2}R_A(\tfrac{1}{2}I)^2 + \tfrac{1}{2}R_B(\tfrac{1}{2}I)^2 + \tfrac{1}{4}2R_{AB}I_AI_B)$$

and dividing by I^2 we get the resistance

$$\tfrac{1}{2}(R_A + R_B) + \tfrac{1}{2}(2R_{AB})$$

where R_{AB} is the extra resistance due to the overlapping currents.

It is not difficult to show that if R is the resistance of the single wire, then the resistance of the two in parallel placed so that they subtend an angle 2ϕ at the surface of the earth is $\frac{1}{2}R(1 + \cos^2\phi)$, which is practically $\frac{1}{2}R$ when the wires are so far apart that $\phi = 90°$.

When ϕ is small, the resistance is nearly R. This is as it should be: for when the wires are close compared with their height above the earth the magnetic field, at the surface of the earth, of the two wires each carrying the current I, is almost indistinguishable from that of one wire carrying the whole current $2I$ for which the resistance is R. In the case where there are N wires in the screen an extension of this process leads to the result that the resistance of all the screen

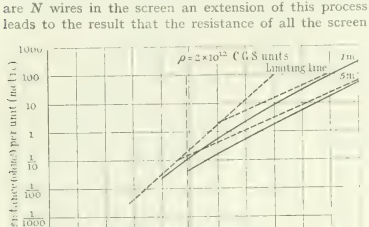


FIG. 12.—Eddy-current resistance loss.

wires in parallel is $R \times f(N)$, where R is the resistance of one of the wires and

$$f(N) = \frac{1}{N}\left[1 + \frac{2^N - 1}{N}\cos^2\phi + \frac{2^N - 2}{N}\cos^2\phi_2 + \ldots + \frac{2^N - r}{N}\cos^2\phi_r + \ldots + \frac{2}{N}\cos^2\phi\right]$$

where $\tan\phi_r = \frac{1}{2}rd/h$ and d is the distance between the wires.

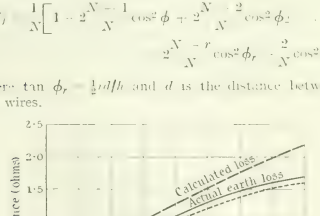


FIG. 13.—Eddy-current loss.

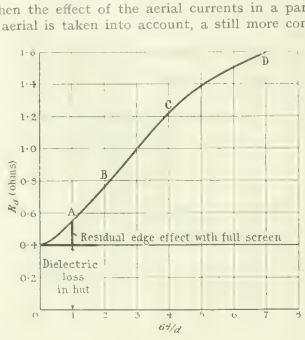
Spacing of wires constant; total span varied.

It is obvious, then, that if the wires are sufficiently few and far between, the resistance will be inversely proportional to the number of wires, but that when the wires are so crowded that the distance between them is small compared with their height above the ground, an increase in the number of wires will not appreciably reduce the resistance.

These are the characteristics of the curves actually obtained, but the numerical values calculated from the above formula with known resistivity and frequency are about 8 times the actual values observed. This discrepancy is due to the neglect of the effect of the currents in the aerial wires which, acting in the opposite direction to those in the screen, reduce the electric and magnetic forces at the surface of the earth (and consequently the losses) about eight-fold.*

THEORY OF EARTH LOSS.

When the effect of the aerial currents in a parallel wire aerial is taken into account, a still more compli-



Screen wires all spaced 1 in.

FIG. 14.—Dielectric loss.

Wave-length, 1 000; spacing constant; total span varied.

cated formula is obtained, which, however, has the merit of agreeing fairly closely with the observed results. The formula is:

$$R = R_0\left\{f(N) + 2\left(\frac{h_0}{2h_1} - \frac{2h_0}{h_1 + h_0}\sum_{r=1}^{r=N}\sum_{S=1}^{S=M}\frac{\cos^2\chi_{rs}}{MN}\right)\right\}\dagger$$

where R_0 = resistance of a single wire; h_0 = height of screen; h_1 = height of aerial above the ground; $\tan\chi_{rs} = \frac{d_{rs}}{h_0 + h_1}$, where d_{rs} is the horizontal distance

* The formulæ for a single wire and screen have been fairly closely checked by experiments on isolated wires and screens.

† This formula is only accurate when the aerial wires are closely bunched together.

The accurate formula is

$$R = R_0 f(N) + R_0 f(M) - 2R_{h_0 h_1} + \ldots \quad \sum_{r=1}^{N}\sum_{S=1}^{M}\cos^2\chi,$$

where R_{h_0} = eddy-current resistance of single wire at height h_0 above the ground,

R_{h_1} = eddy-current resistance of single wire at height h_1 above the ground,

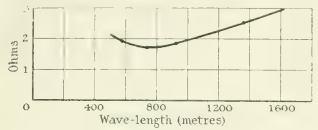
$R_{\frac{1}{2}h_0 + h_1}$ = eddy-current resistance of single wire at height $\frac{1}{2}h_0 + h_1$,

and $f(M)$ is the same function of the M wires of the aerial as $f(N)$ is of the N wires of the screen.

between the rth wire of the screen and the sth wire of the aerial; M = total number of wires in the screen; and N = total number of wires in the aerial.

In the curves, the calculated results have also been plotted and it can be seen at a glance that the results agree remarkably well in form if not in absolute value.

This theory is confirmed by the second set of experiments in which the mean breadth of the screen is reduced, the spacing of the wires remaining constant. The eddy-current resistance separated out from the total resistance by the methods already described is



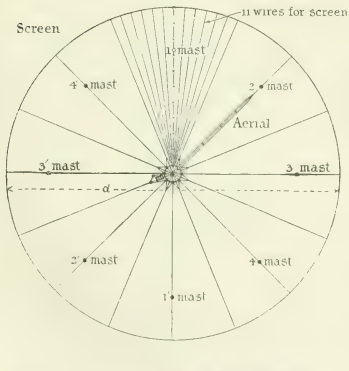


Fig. 15.—T aerial and full screen (6/1/20).

Aerial: same as A in Fig. 1, with cotton-covered wire replaced with bare 7/19 wire.
Screen: as shown above.
Weather: wet.

plotted against $64/d$, where d is the breadth of the screen. It will be seen that when d is large, the resistance is nearly inversely proportional to d, that is, the wider the screen the less is the resistance up to a certain limit.

This is always the case with the screen resistance alone, for, as in the previous explanation, the wider the currents are spread, the less total loss there is.

The limited breadth of the aerial partly modifies these results, for when the screen spreads widely beyond the limits of the aerial the currents are no longer shared equally by all the wires of the screen, but are concentrated in those below the aerial, so that additional wires in the screen beyond a certain distance do not appreciably reduce the resistance. According to the theory, the shielding of the aerial by the currents in the screen wires would be reduced if the screen wires were spread too wide and the total current were shared equally among them. For in the limiting case, when the screen was extremely wide there would be no shielding of the effects of the currents in the aerial, as the currents in the screen wires would all be too small to produce any appreciable effect. The aerial resistance can be reduced only by widening the aerial and screen together; this, however, has certain attendant disadvantages which will be alluded to in a later part of the paper. The calculated curve (in which, by the way, a uniform distribution of currents in the screen is assumed) is plotted, as well as the observed curve, and again the agreement in form is remarkable and, in absolute value, is within the limits of experimental and theoretical errors.

Further Experiments on Radial-type Aerials.

These conclusions with regard to the earth loss have been verified in numerous experiments with various

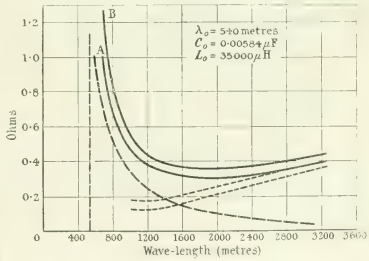


Fig. 16.

Aerial: 32 wires at mean height 18·5 m., equally spaced radially.
Screen: 88 radial wires about 1·5 m. above ground, each 200 ft., 78 m. long, supported on central steam posts with 2 concentric rings of iron posts and 1 inner ring of timbers.
Weather: fine and dry.
Curves B: as in curve A except that the extra cross wires were still in the screen.
Curve B: $R = 0{\cdot}082 + 1{\cdot}000/\lambda^2 - 0{\cdot}054\lambda/1{,}000 + 0{\cdot}035\lambda^2/1{,}000^2$.
Curve A: $R = 0{\cdot}058 + 1{,}000/\lambda^2 - 0{\cdot}044\lambda/1{,}000 + 0{\cdot}018\lambda^2/1{,}000^2$. Screen cross wires removed.
Radiation $R\lambda_{200} = 0{\cdot}72$ ohm (calculated).
Radiation $R\lambda_{200} = 0{\cdot}77$ ohm (from mean of curve A).

types of aerials. In particular, a large set of measurements was made on a radial type of aerial consisting of eight 4-wire sausages, radiating from a central 70-ft. mast to eight similar masts, equally spaced in a 200-ft. circle, together with a radial form of earth screen of 88 wires 4 ft. 6 in. above the ground, arranged like the spokes of a bicycle wheel (see Fig. 15).

Numerous resistance curves (R plotted against λ^2

were obtained and analysed into their component parts:

(*a*) Radiation resistance $1\,580/\lambda^2$ (calculated);
(*b*) Earth loss $\alpha/(\lambda)^{\frac{1}{2}}$;
(*c*) Dielectric loss $\alpha\lambda$;
(*d*) Leakage loss $\alpha\lambda^2$.

Measurements were made under very varying conditions, but the earth loss analysed out from the curves remained remarkably constant so long as the disposition and height of the wires in the screen were unaltered. Even when the aerial was lowered to half its original height no appreciable change was produced.

This might at first sight appear to contradict the theory which attributes the earth loss to a differential effect between the aerial and earth, but it can be shown that so long as the screen entirely shields the aerial from the earth, and the aerial is not too high, the loss is hardly affected by varying the distribution and height of the aerial wires, although, of course, the best results are obtained by spreading the aerial as uniformly

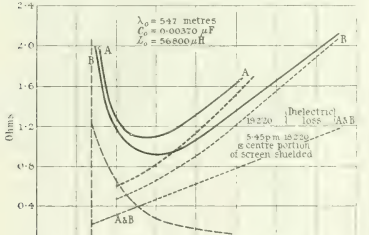


FIG. 17.—Showing effect of screening centre portion.

Aerial: 8 sausages tall height. Rope halyards replaced by flexible wire, otherwise as before (steel wires insulated).
Earth: as before.
Screen: as before.
Weather: fine, but grass wet.
A 18/2/20 before screening.
B 19/2/20.

$R = 0{\cdot}18\,1\,000/\lambda^{\frac{1}{2}} + 0{\cdot}375\,\lambda/1\,000$ — 0·154 λ/1 000² before screening centre.

$R = 0{\cdot}096(1\,000/\lambda)^{\frac{1}{2}} + 0{\cdot}382(\lambda/1\,000)$ — 0·092 λ/1 000² after screening centre.

as possible over the earth screen. The curves in Figs. 16 and 17 give a notion of the diversity of material out of which the same earth loss has been derived. Fig. 16 shows the best results and Fig. 17 the worst, the difference between the two being almost entirely due to the difference in the dielectric and leakage losses.

The minimum resistance in Fig. 16 is actually equal to 0·3 ohm at $\lambda = 1\,900$, about $3\frac{1}{2}$ times the natural period of the aerial, and a radiation efficiency as great as 33 per cent is obtained here.

The theory of the aerial and screen is thus fairly complete as regards earth losses; and the salient point is that further reduction of these losses can be made only by increasing the width of the aerial and screen together.

The other losses are more difficult to deal with, as they are less definite and depend more upon the accidental presence of bad dielectrics in the field of the aerial.

Other Losses.

These can be mostly eliminated by careful design of insulators, supports, etc.

The effect of bad design is illustrated by the results obtained when the screen was supported on a large number of wooden posts. Curves A and C (Fig. 19) show how a large amount of the dielectric loss may be removed by replacing the wooden posts with iron ones. The dielectric loss in wood is very susceptible to dampness and increases to nearly twice its ordinary value when the wood is very wet. The use of wooden supports is therefore objectionable on two accounts: (*a*) on account of the resistance they introduce, and (*b*) on account of the variability of this resistance with dampness. This variability is not accounted for by leakage, as the loss proportional to λ is susceptible to it.

Surface Dielectric Loss.

As before stated, losses of this kind can generally be removed by careful design. There appears, however, to be one loss which is definite and to a great extent unavoidable. This occurs in the surface vege-

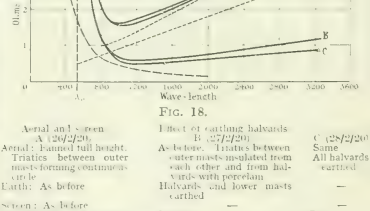


FIG. 18.

Aerial and screen	Effect of earthing halyards
A 12/2/20.	B 27/1/20.
Aerial: Tinned tall height.	As before. Triatics between outer masts insulated from each other and from halyards with porcelain	C 28/2/20 Same. All halyards earthed.
Triatics between outer masts forming continuous circle		
Earth: As before	Halyards and lower masts earthed	—
Screen: As before	—	—
Weather: Fairly dry, windy	Drying	Dry

(A) $R = 0{\cdot}13\left(\frac{1\,000}{\lambda}\right)^{\frac{1}{2}} + 0{\cdot}90\left(\frac{\lambda}{1\,000}\right) + 0{\cdot}125\left(\frac{\lambda}{1\,000}\right)^2$

tation of the earth, and can be only partly shielded by the grid of screen wires. This point is illustrated by the result of the experiments with the inverted L-type aerial already described.

The dielectric resistance is plotted against the number of wires in the "A" experiments and against $64/d$ in the other set (Figs. 10 and 14). It will be seen that in both sets of experiments the loss tends to a certain limiting value, which is the same in both. This minimum loss was found to be, in a sense, accidental, for it was discovered to lie in the lead-in to the hut, which was made of wood, a very bad dielectric. The loss was afterwards removed by putting in an ebonite panel.

The remaining loss which varies with the distribution of the wires of the screen is more essential and has, as

before stated, finally been traced to the surface layer of vegetation on the earth. This is naturally suggested by the fact that it varies with the distribution of the screen wires.

The "A" experiments indicate a very rapid increase of the loss with the increase of the spacing of the wire (Fig. 10). The quasi-stationary theory is important here, for it is the electric force *perpendicular* to the earth which is responsible for the dielectric loss, and it therefore varies in accordance with this theory. The increase of the resistance with the spacing bears a strong resemblance to the leakage curve based on Maxwell's theory of the grating, and there seems little doubt that the leakage force through the screen and over its edges is responsible for the loss.

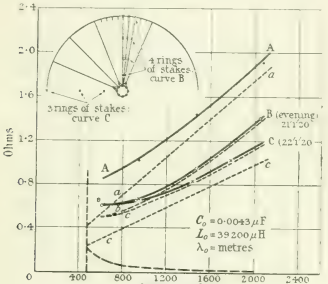


FIG. 19.—Effect of removing stakes.

A and B aerial: Sausage-shaped top as before. $h = 20$ ft. approximately.
Earth: As before.
Screen A: As before—all stakes driven 21/7/20. 10 rings.
Screen B: 4 stakes removed as in upper figure. 4 rings only.
Screen C: 3 rings of stakes 22/7/20.
Weather A }
Weather B } Fairly dry.
Weather C }
(A) $R = 0{\cdot}17\,\{1000/\lambda\}^2 = 0{\cdot}87\,\lambda/1000$.
(C) $R = 0{\cdot}16\{1000/\lambda\}^2 = 0{\cdot}48(\lambda/1000)$.

The dotted curve (Fig. 10) shows the calculated value, assuming a loss knX^2 per unit area, where X is the electric force perpendicular to the surface of the earth, n is the frequency, and k a constant, the specific loss per unit area. The value of k used is $(2 - 3) \times 10^{12}$ (this value of k is in fair agreement with the value derived from other sources), in which case the expression for the resistance due to this cause is

$$R_i = \frac{4k}{\pi n} \cdot \frac{l}{lNd} \cdot \frac{e^{-2\pi hl/d}}{\sinh(2\pi hl/d)},$$

where l = length of the screen wires in cm;
n = frequency;
d = distance between wires in cm;
N = number of wires;
h = height above ground of wires in cm.

The "B" experiments Fig. 11 show how nearly the edge effect has been eliminated in this particular screen, so that an overlap equal to the height of the aerial seems to be sufficient.

Experiments on the radial aerial confirm these conclusions, and a comparison between the earthed and screened aerials is very instructive. With the earthed aerial, a relatively large amount of dielectric loss remains even when all the suspicious dielectrics have been removed.

With the screened aerial the loss is only about 7 per cent of this, which is in good agreement with the calculated reduction, assuming that the leakage is in agreement with Maxwell's formula.

Determination of Surface Loss.

These and other reasons make it probable that this remaining loss is due to the surface vegetation, the more so, as it can be shown experimentally that this loss at the surface is a large fraction of the energy stored there. Two plates, 6 ft. by 3 ft., were placed over the surface of the grass so that they formed two condensers in series, as shown in Fig. 20.

The dielectric loss of this system was measured at various frequencies and it was shown that from 10 to 20 per cent of the energy stored in this condenser was dissipated per period. Since the surface layer, which is only about 1 ft. in thickness, is only a small fraction of the height of the aerial, only a small fraction of the total electrostatic energy is stored in it, and even though a large fraction of the energy stored in the layer is dissipated per period this only amounts to quite

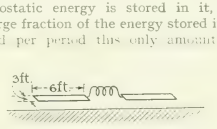


FIG. 20.

a small proportion of the total energy, and the dielectric loss assumes reasonable proportions.

Given a knowledge of the specific dielectric loss per unit area of the ground, it should be possible to calculate the total dielectric loss with any form of aerial. This constant will enable us to predetermine the dielectric-loss resistance of an aerial, just as a knowledge of the resistivity of the earth enables us to calculate the earth loss. Thus, when the geometrical form of the aerial is given, it should be enough to know these two constants to be able to calculate the total resistance of the aerial (assuming that we can calculate the wire and radiation resistances from the ordinary formulæ, and that the leakage loss is negligible).

This ability to calculate the resistance is very desirable in the case where new aerials of a large size have to be erected, for it enables us to design accurately and predetermine the whole performance of the aerial.

Model.

If the calculations are not considered trustworthy, or if further confirmation of these is required, recourse may be had to a small model of the proposed aerial.

The resistance measurements made on such a model can be used to predict the resistance of the large aerial by the use of a principle of similarity if due regard is paid to the difference of the constants k and ρ at the two sites.

It can be shown that if the dimensions of the model are in the ratio of S to 1, then at corresponding wave-lengths, i.e. λ on the model and $S\lambda$ on the large aerial,

(*a*) the eddy-current resistance is reduced $1/\sqrt{S}$ times ;
(*b*) the dielectric loss is reduced $1/S$ times ;
(*c*) the leakage loss is the same.

So that even better results than those obtained on the model may be expected, on a large long-wave aerial.

Screen Oscillation.

The discussion of the screened aerial is not complete without mention of some curious effects which were first observed in circular types of aerials, and later in inverted L and T aerials.

The effects first showed up as a very rapid increase in resistance at wave-lengths close to the natural wave-length of the aerial, an increase which was much too rapid to be accounted for by any change in the eddy currents or radiation resistance. It was later discovered that at still lower wave-lengths the resistance decreased again. The resistance curve, therefore, showed a peak in the neighbourhood of some wave-length near the natural λ of the aerial. It was natural to suppose that this peak was due to the presence of some oscillation of that particular period, and a short search resulted in the identification of this with the wires of the screen which, having, for an end-to-end oscillation, a natural period of this amount. A glance at Fig. 21 will make this clearer. This diagram represents the elevation of such an aerial, which, it may be observed, has at least three possible modes of oscillation. These are shown in the diagram, and the arrow represents the path of the current for each particular mode of oscillation.

No. (1) is the main oscillation which is responsible for the radiation of energy.

No. (2) is the oscillation from end to end of the screen, to which reference has already been made. This may obviously absorb a great deal of energy if present and, since it does no useful work in radiation, it is in every way harmful.

No. (3) is the oscillation from end to end of the aerial and is normally outside the working range of wave-lengths ; for that reason it can be neglected. The oscillation (2) is usually somewhere near the natural period of (1), and hence is dangerous when working on the shortest wave-lengths.

We might, at first sight, be led to infer from the symmetry of the aerial that no oscillation of the type (2) should be produced when an E.M.F. is induced solely in the vertical part of the aerial. Apart from the difficulty of satisfying the last condition, absolute electrical symmetry is almost impossible to attain, in which case the point of attachment of the aerial to the screen will not be at a node of potential of the oscillation (2). The existence of an oscillation (1) will then necessarily produce the other oscillations ; in fact the oscillations (1) and (2) are not independent unless the aerial is attached at the node of (2). Again, if the height of the aerial is greater on one side than on the other, the symmetry will be destroyed and oscillations of type (2) will be forced. Anyone who has experienced the difficulty of completely balancing a pair of direction-finding aerials or any other high-frequency bridge balance will not be surprised to find that an aerial of this kind generally exhibits oscillations of the type (2) near the latter's natural period, unless special precautions have been taken to eliminate them.

One method of doing this is to earth the point O

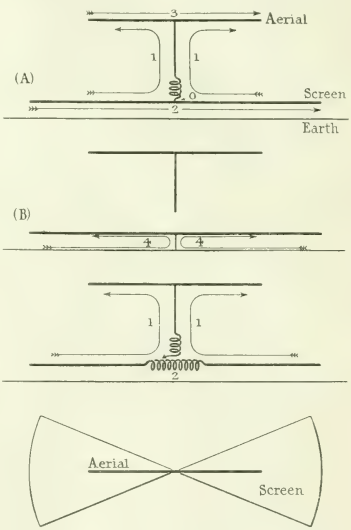


Fig. 21.—Independent free periods of the screen.

where the screen is joined to the aerial. This forces O to be a node of potential and so destroys the coupling. The method has been found fairly effective, but it does not reduce the resistance to its normal value in the neighbourhood of the natural period of (2). It has two disadvantages which may be serious in certain cases :

(*a*) It introduces still another oscillation of the type (4) in which the earthed screen acts as a miniature T aerial of a longer wave-length than the natural period of (1). (See Fig. 21B.)

(*b*) The second disadvantage is that the point O will not, in general, be a natural node of potential of the oscillation (1). To earth this point will therefore introduce earth currents which it is the function of the earth screen to avoid.

In an inverted L-type aerial, the earthing of the point O generally leads to about 50 per cent increase in the resistance. It has, however, been discovered that a point on the loading coil can be found which can be earthed without increasing the resistance.

This is a point of considerable practical importance, for it enables the potentials of the whole system to be stabilized by earthing a definite point.

Since in general the point O is not a natural node it cannot be earthed without introducing extra resistance, and it is therefore preferable to try to balance up the

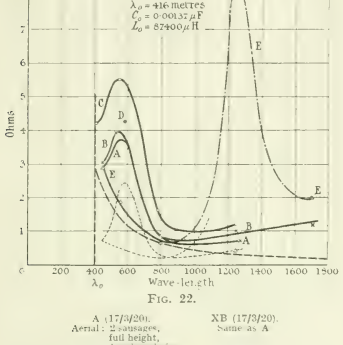


FIG. 22.

	A (17/3/20).	XB (17/3/20).
Aerial:	2 sausages, full height, details as before	Same as A
Earth:	As before	As before
Screen:	As before	As before
Weather:	Fairly dry	Damp

C as in A and B 18/3/20).

system by other means. These will naturally suggest themselves to anyone who has dealt with such problems.

Fig. 22 shows some typical resistance-wavelength curves which illustrate these points. They refer to the radial type of aerial. A, B and C are obtained when O is not earthed, E with O earthed. The presence of

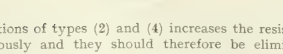


FIG. 23.

oscillations of types (2) and (4) increases the resistance enormously and they should therefore be eliminated at all costs.

In the first experiment with inverted L-type aerials no effects of this type were observed, but this was probably because the aerial and screen were rather long and narrow. With a broad and comparatively short aerial, the case is different and effects due to spurious oscillations become more prominent. These effects were first noticed by Mr. Lunnon when measuring the resistance of the Clifden aerial and screen, in which he found a very rapid rise in resistance near the natural period of the aerial. This he attributed to an oscillation in the screen, of a type not previously investigated.

The currents carried by the wires of the screen should be all equal. The nature of the oscillation contemplated by Mr. Lunnon is one in which the currents go down the centre and up the sides of the screen, and vice versa. These oscillations are liable to occur when the length of the outer wires differs largely from that of the centre wires as in the case of a short, broad screen, for the node of this oscillation is then not at the point of junction of the wires and aerial. Again, if the aerial is narrow and placed centrally over the middle of the screen, the differential action of the currents in it on the centre and outer conductors (B and A respectively) will tend to produce oscillating currents round the circuit AB, etc. (see Fig. 23). Such a system in which these effects have been exaggerated by suitable design has been investigated, and a large increase in resistance occurs on the natural period of the circuit AB and represents the extra loss due to the oscillations in this circuit. This loss can be partly avoided by strapping together the ends of the screen wires, but this practice introduces losses in circulating currents round the closed circuits formed by these connecting wires.

A simpler way is to make all the wires the same length, but even when this is done there is still, due to the differential action of the aerial, an E.M.F. round the circuit AB. This can be minimized by spreading out the aerial as widely as possible.

The effect of these oscillations may be removed by suitable design of aerial and screen. The resistance is perfectly normal except in the neighbourhood of the spurious oscillations, and the maximum increase in resistance at this wave-length is only about 0·12 ohm.

General Conclusions.

The questions raised by this investigation have a very general bearing on wireless practice. We may, in fact, ask ourselves how far we may go on reducing the losses. The very favourable results so far obtained seem to augur a possibility of obtaining even better results in the future. There is still considerable room for improvement, for the earth losses in the cases already investigated still form a large proportion of the total resistance.

The lines along which further reductions in earth loss may be effected are indicated by the theory, which shows that a simultaneous broadening of the screen and aerial have the desired effect. Again, the dielectric loss may be reduced by spacing the wires more and more closely or by using a complete radial screen in which the edge effect is reduced to a minimum.

Screens have been employed successfully at large power stations, for example at Clifden, and it now requires only one-sixth of the power to produce signals at Glace Bay equal to those formerly produced by the spark station. It is evident, therefore, that the practice of long-distance wireless telegraphy may be very considerably modified by these results.

Obviously, if perfect radiation efficiency can be obtained, the height, size, and shape of the aerial will not matter so long as it radiates in the direction required; for all the power put into the aerial is usefully employed in radiation. But when a small or low aerial is used we are likely to experience other troubles. If, for instance, we halve the effective height we must double the current to produce the same range; in fact, the currents required are inversely proportional to the heights. For this reason the currents with a low aerial tend to become excessive and, before long, the voltage limit of the aerial may be reached. Take the same example again; if we halve the height, we must double the capacity for the same maximum voltage in each case, and so on; lowering the aerial to half the height will in most cases hardly increase the capacity, so we shall have to spread the aerial to attain these results.

The practical point is this: It is much cheaper to erect an aerial of 400 ft., say, with 40 jars' capacity, than an 800-ft. aerial with 20 jars' capacity, and even cheaper still a 200-ft. aerial with 80 jars' capacity. The height rather than the area is the difficulty. Now, if sufficient care is paid to the improvement of the resistance, the height of the aerial can be reduced without increasing the power required to produce a given range, and in the limiting case a closed directive aerial might be used to minimize jamming and to increase the effective radiation in the direction required, with a plate condenser which would effectively control the maximum voltage.

This condition of affairs is not possible when the dead-loss resistance is large compared with the radiation resistance for, when this is so, every decrease in height requires a commensurate increase in power. The ideal case of perfect radiation efficiency has been assumed, and, although this can never be obtained in practice, the reduction of the dead-loss resistance will always mean: (*a*) an economy in power required; (*b*) an economy in initial expense on aerials by enabling a lower aerial to do the work of a higher one.

It is desirable to consider whether the resistance can be reduced in any other manner. Naurally the Alexanderson multiple-earth antenna suggests itself, and perhaps a rough comparison would not be out of place in this paper. By putting the earth losses in parallel, so to speak, instead of in series, the resistance is reduced in the ratio of $n^2 : 1$, where n is the number of earths; but this is emphatically not the case with the dielectric loss, which is left unaltered by this method of earthing and, as we have seen, forms the major portion of the loss on wave-lengths which are long compared with the natural λ of the aerial.

Any reduction of the surface dielectric loss can be made only by suitably screening the earth. Of course, a combination of the two systems may be used and may in certain cases be preferable, as for example in the case of long, narrow aerials; the multiple earthed aerial suffers, however, from the disadvantage that it cannot be allowed to oscillate freely, since it has so many possible natural periods, but must be forced to respond to a machine or apparatus of definite frequency which cannot be easily reacted upon.

There is, however, no doubt that in the case of certain existing aerials it is preferable to reduce the resistance by the Alexanderson method. This is especially so in the case of long, narrow aerials. The screening of such an aerial may not reduce the resistance sufficiently and it is a matter of great practical difficulty to widen an existing aerial and reduce the resistance in this way. The only alternative is to make use of Alexanderson feeders and to put the various sections of the aerial in parallel instead of in series, which is, in effect, equivalent to a simultaneous widening and shortening of the aerial. But to get the best results from this method a suitably designed screen should be used to intercept the lines of force from the aerial and to reduce, consequently, the surface dielectric loss.

In conclusion, whatever the drawbacks of the screened aerial may be, it is certainly one degree nearer the ideal of perfect radiation efficiency.

I should like to express my thanks to Captain Round for his valuable help and suggestions throughout the work, and to Mr. Lunnon for his invaluable assistance in the experimental work.

Discussion before the Wireless Section, 7 December, 1921.

Major J. Erskine-Murray: The part of the paper which interests me most is the work covered by Fig. 21, on the losses in various parts of the aerial. As far as I know, that work is thoroughly new and is of great value. The rest of the paper appears to me to suffer a little from neglect of what has been done before. I should like to make a few remarks on the work which leads up to this investigation. I think that the author has been put off the real essence of Lodge's results by the latter's insistence upon the question of the height of the lower capacity or screen. Except that it is smaller than the author's screen, Lodge's lower capacity is the same. Now Lodge, in 1909 in a well-known paper,* showed that an aerial with a screen below it gave much stronger signals than a conductively earthed aerial; he thought he was altogether avoiding earth effects by using the screen. I think that in some respects the author follows him a little too closely in thinking that the screen really has this effect. I am afraid it does not. There is no doubt, however, that Lodge did show definitely, in his resonance curves, that he had obtained a very much lower decrement, and therefore a lower antenna resistance, though he does not mention the fact. He also showed that there is a maximum efficiency for a definite height of screen. The author appears to have kept to one height, and of course one sympathizes with him, for it is not practicable to shift 66 wires through any great height. Lodge had a simpler system, a single Maltese cross which was only the same size as the upper part of the aerial. In order to illustrate this, suppose A to be the upper part of the aerial and B that which we call the screen or counterpoise, while E is the earth, A

* *Proceedings of the Royal Society*, 1909, vol. 82, p. 227.

and B being joined by a wire containing inductance. In Lodge's case it actually had spark-gaps in it. We have between A and B a capacity which we can call C_1, between B and E a capacity C_2, and between the upper part of the antenna and the earth a capacity C_3. It is legitimate, I think, to split these capacities, because there are lines of force which go to E from A, and, as we know, this part of the antenna circuit really extends to something like three-quarters of a wave-length. That is to say, a line from the top of A goes to E and comes up again from E to the lower side of B. The greatest density of lines is close by, but still there is something happening beyond the screen. The circuit can be represented in this way: capacity C_1 and these two other capacities in series C_2 and C_3 but in parallel with C_1. Lodge says that the best radiation by experiment is obtained when this total capacity is a minimum. The total capacity C is equal to C_1 and C_2 in parallel and C_2 and C_3 in series; that is, $C_2C_3/(C_2 + C_3)$. Let us call h the height at B and H that of the top. If dC/dh is equated to zero we shall obtain a maximum or minimum. The capacity C_3 is constant if the aerial be kept constant in height. Also, C_2 varies as the area of this lower capacity divided by the height, and C_1 varies as the area divided by the height $(H - h)$. If we differentiate, we see that $C_1 = C_2C_3/(C_2 + C_3)$, that is to say, the two capacities in parallel must be equal in order to get a minimum total capacity. There is also a little inductance in each side—something very small, but still sufficient to differentiate these two as separate circuits. The condition is therefore that the external and internal circuits are tuned. This explanation is, I believe, new. The form of earthing shown in Fig. 1 was common long ago, but in 1911 I stated in my "Handbook" (and it was common knowledge then) that a much better earth is usually obtained by burying a number of wires corresponding in length and capacity to the aerial itself. I think, therefore, that if this earth was of the zinc-plate type on a small circle, the author has taken a poor sort of earth for comparison. There was another case about the same time. In 1912 I advised that the aerial at Ballybunion should have a screen under it, but in that case the difficulty was cows. The owners said they could not afford to lose the rent of the land as they would if they could not keep cows on it. They could not put the screen high up above the cows as it would be too expensive, so the screen was not tried on a large scale in that case. As regards previous measurements resembling those of the author, I think that the work of H. True * ought certainly to be mentioned, as it was extraordinarily painstaking. He worked both with the earthed aerial and with an aerial with a lower screen equal to the top, and he measured the drop in potential due to the currents in the earth all round that aerial, at various depths. The general result obtained was that in an antenna with a screen the damping is less for all wave-lengths than in a conductively earthed antenna. He also mentioned that the damping is decreased as the height of the screen is increased. As regards actual aerials, Austin in 1913 measured the resistance of the large aerial at Arlington near Washington. That is a triangular aerial 600 ft. high at one point and 450 ft. high at two other points. At 4000 metres wave-length he found that the resistance was only 1·8 ohms. In this case he had a large earthed network extending considerably beyond the antenna in every direction. Zenneck, in the second edition of his book published in 1913, remarks that it makes no qualitative difference as regards the course of the current lines in the earth whether the net is used as an earth connection or as a counterpoise. He remarks also that it does make a quantitative difference; he gives also a number of interesting figures which are worth referring to. I do not like Fig. 4B because, if it is drawn more or less strictly from Maxwell, it deals with infinite plates and an infinite number of parallel fine wires. Also I do not quite understand what happens to the lines of force coming from the top of the aerial. They apparently go off into space, with the exception of one which manages to get into the last screen wire. I do not see why there are so few of them. Prof. Howe has shown that the capacity of an elevated aerial when it is reasonably high up does not vary very greatly with the distance from the earth. The consequence is that there must be nearly as many lines of force going off from the top as from underneath. All these have to be accounted for. They have to come to earth somewhere at a good distance from the aerial. Therefore I do not know what is going to happen to those little lines coming down between the wires of the screen in Fig. 4B, because there are lines going up at the same place, since there are bound to be lines coming up somewhere. What was the resistance of the earth in Fig. 5? What kind of earth was it, because here again we have no basis for comparison? On page 589 the author says: "The limited breadth of the aerial partly modifies these results, for when the screen spreads widely beyond the limits of the aerial the currents are no longer shared equally by all the wires of the screen, but are concentrated in those below the aerial, so that additional wires in the screen beyond a certain distance do not appreciably reduce the resistance." I think there is another reason, besides that given by the author, which would be worth his investigation, viz. that if we have a screen of parallel wires the lines of force over it are travelling out and in, to a greater or less extent, and not all parallel to the wires. On getting far enough out the lines of force must be radiated from the side of the aerial and therefore they are cutting the outer parts of the screen. That does not happen, of course, in the radial aerial shown in Fig. 15, and therefore a better result is obtained there. The author has got really good results mathematically which compare well with his experimental results, and has placed the whole thing on a satisfactory basis for calculation.

Major R. C. Trench: Those who work with both the counterpoise and the conductive earth always realize that the counterpoise will give the better radiation efficiency; but a scientific analysis, such as the author aims at, is a very different thing from the mere knowledge of the fact. In view of the great discrepancy in the efficiencies of the two systems which

* *Jahrbuch der drahtlosen Telegraphie*, 1911, vol. 5, p. 125.

the author found, I share Major Erskine-Murray's curiosity as to what actually the conductive earth consisted of, and if it was given a fair chance in competition with the counterpoise, by being made according to the best principles, with no pains spared to reduce resistance. It would be interesting to know whether the author considers that the proportion of the earth losses, which he was unable in the end to eliminate—the residue of the earth losses after the screen had been made as perfect as possible—could be reduced to any further extent by a surface network of wires not connected in any way to the system but simply laid on the earth, giving the earth's surface an artificial high conductivity. The author points out at the end of the paper the importance of symmetry in the connections to the screen. This is extraordinarily important in practice. A case in point was a screen which consisted of 8 wires, 20 ft. apart and 300 ft. long, which were connected first by one single transverse wire which was not at the central point, with the lead-in wire soldered to one point of the transverse wire—a thoroughly unsymmetrical connection. Not more than 3 amperes of aerial current could be obtained in a 2-kW set on just over the natural wave-length. This unsymmetrical connection was replaced by one as nearly symmetrical as it could be made, and the aerial current immediately rose to 10 amperes. The author makes no reference to the possible effect of the total capacity of the aerial, and the effect on the total capacity of the size of the screen. The bigger the screen, the nearer would the total capacity of the aerial to earth approach that of the earthed aerial. Did the author make any experiments in regard to receiving with a screened aerial? I have found consistently that a screened aerial, although it will send much more efficiently than the same aerial does when earthed, will at the same time receive much less efficiently. I do not attempt to account for it.

Mr. J. E. Taylor: I think that the earth screen is the most important thing described in the paper. Valves are referred to, but they are of secondary consideration in connection with efficiency of transmission. I have a way of viewing the screening action which differs from that put forward in the paper. If we enclose a wireless transmitter entirely in a network screen or Faraday cage and set it working, we get nothing outside. If we make an aperture sufficiently large in that screen we shall get some radiation issuing, but its screening action need not be appreciably impaired. Obviously the screen may be so arranged as to form the antenna and earth systems of the transmitter. The author's method of regarding it may lend itself better to mathematical analysis, but even on that point I am doubtful, because all that happens outside the screen is caused by whatever leakage effect can be obtained due to the dividing aperture in the screen, and it seems to me that the leakage should be more directly calculable. I recently looked up a number of data bearing on this earth-screen question. One of these sums up the plan better than any of the others. It is dated 11th February, 1913, and reads: "Patents.—Apply re-use of wire network or other conducting screen for the purpose of confining the oscillating field to the dielectric space between aerial and screen, such screen forming a surface of any desired shape, so disposed as to screen off parts of the building or installation and prevent oscillations being directly impressed thereon. Object: To confine oscillating electro-magnetic field to as pure a dielectric as possible, and prevent brick walls, earth's surface or auxiliary parts of the installation from causing losses." That is not pure guesswork. It was partly based on experiments which had been carried out by other people, but which had been, in my view, misinterpreted, as wireless tests so often have been in the past. I have all along felt quite sure that that was the right direction in which to work, and I am glad to see that there is at last a prospect of the abandonment of what I have felt to be the unscientific plan of burying earth wires in the ground for a wireless transmitter. I think this is an instance of the great desirability of getting proper and correct general views of the actions concerned in wireless transmission. I should like to ask whether any special insulation troubles were encountered in the application of this earth screen to transmitters using continuous waves.

Lieutenant G. W. N. Cobbold, R.E.: I have been particularly interested in this paper owing to the fact that I myself have been engaged, in conjunction with Captain Hughes, of the Royal Corps of Signals, at the Signals Experimental Establishment, in carrying out a somewhat similar series of experiments. We have undertaken, during the course of the past two years, the measurement of the electrical constants of most of the different military types of aerial, all of which have comparatively low transmitting efficiencies. Various earths and balance capacities have been used, and experiments have been made under various different conditions of weather. Some 50 or 60 resistance-wave-length curves have been obtained, but the accuracy of the portable instrument we used is not extremely great; and we shall not feel justified in making an analysis similar to that undertaken by the author until radiation measurements can be carried out to check the analysis. I should like to know if the author has carried out any radiation measurements by way of a check on his mathematical analysis; for unless that is done it seems that extremely accurate measurements are essential, and that a very slight change in the curvature of his curves would result in considerable errors in the determination of radiation efficiencies. Our results, so far as they go, confirm what the author has found, i.e. that a great reduction of the total effective resistance of an aerial is produced when a balance capacity is used in place of an earth. We have not yet, however, been able to discover to what extent the radiation efficiency increases; in fact, it has not yet been proved, with such balance capacities as we have used, that the radiation resistance is not reduced at the same time as the total resistance and in something of the same proportion. Of course this will depend to a great extent on the design of the balance capacity or earth screen employed. There are one or two questions I should like to ask the author which are particularly appropriate to the line of work on which we are engaged. I am very anxious to hear if he has carried out any

experiments in order to discover whether the height of his balance capacity or screen is at all critical, or to determine whether a very serious loss occurs if the length of the screen is equal to and not greater than the length of the aerial; for under mobile conditions it might be very much easier to use an earth screen of the same length as the aerial, and it might be a considerable advantage if the height of the screen could be increased. I do not know how far the statement concerning the improved ratio of received signal strength to transmission power in the case of Cliden signals can be taken to demonstrate the value of the earth screen. It would appear that at the same time as the change-over was made from an earth to an earth screen the method of transmission was converted from the spark to the continuous-wave system. It seems to me that, as it stands, this statement is of little value from the point of view of comparing earth screens with earths, unless at the same time some idea is given of the amount of improvement due to the change from the spark to the continuous-wave system.

Major H. P. T. Lefroy: I am much interested in the author's explanation of certain results obtained with screened aerials, because the Army has used this type of aerial since 1904 in various forms, and in 1908 adopted, as standard pattern for the Army Wireless wagon set, a circular aerial with 12 spokes, each 110 ft. long, in the upper capacity, and 12 spokes, each 160 ft. long, in the lower capacity or "screen." To make the latter practical for field use the inner ends of the spokes were attached to the central mast 7 ft. above the ground, so that men could walk under them; the outer ends were fixed on pickets 2 ft. above ground; only one mast was required, which was 80 ft. high, and of telescopic pattern, so that it could be carried like a field gun. I should like to ask the author whether a symmetrical circular screen, such as described above, can oscillate by itself, and, if so, to describe its mode of oscillation. The results we obtained coincide with the author's results, in that we found the aerial resistance with the screen was about half that obtained with a normal direct earth connection. With regard to sending, I should like the author to say to what extent this decrease in aerial resistance actually gives an increased effective range, with a given primary energy and a given system. Our experience was rather disappointing, as in practice we did not get a much better range than we obtained with a similar aerial having a good direct earth connection. Two things must be considered in connection with the use of screens; first, the electrical advantages of reducing the aerial resistance, and secondly, the effect on the strength of signals received at a certain distance. I suggest that the latter may be a function of the capacity of the screen to earth. When that capacity is infinite, i.e. when the aerial is directly connected to earth, we get a greater resistance, but, at the same time, the effect of the aerial at any given distance from it appears to be maximum; when that capacity is about 0·01 μF the effect of the aerial is probably rather reduced, but this is approximately counterbalanced by the greater aerial current obtained owing to reduction in aerial resistance; for a much smaller screen-capacity, e.g. about 0·001 μF, I think the result of using a screen would be rather disappointing. As an extreme example, there is the case of aircraft aerials, of which the capacity to earth is negligible. I should like the author to give, in his reply, a graph of the effective range relative to this screen capacity. The main use we found for the screen aerial was that, owing to its greatly reduced resistance, and consequently reduced damping, we were able to work our stations, independently, closer together for a given difference in wave-length, than when using an earth connection; e.g. in the Army Manœuvres of 1912 it was found possible, using a rejector, to receive messages from the airship "Gamma," on 300 metres, at a station a few hundred yards distant from a 1½ kW Army wagon set sending on a screen aerial on 600 metres. Another point in its favour is that in Army work we are frequently changing our position; sometimes we are on an excellent earth, such as meadow land near a river or other water, and at other times on a very bad earth, such as heather or dry sandy soil. By using a screened aerial we got a constant aerial resistance and, therefore, constant results on which to base our organization. I should also like the author to give a graph of the change in aerial resistance relative to the height of the screen above ground, and any information which he may possess about the height of the screen relative to the subsoil water level. With regard to receiving, we found that signals were rather weaker on a screen aerial than on a similar aerial with direct earth connection; the probable reason being that in the former case the umbrella aerial was considerably more closed, and, therefore, absorbed energy more slowly, than in the latter case; on the other hand, the screen aerial, on account of its low damping, was more suitable for the use of selective devices, such as the rejector.

Mr. A. C. Warren: On page 590 the author states that in using an earth screen a radiation efficiency of 33 per cent was obtainable at a wave-length corresponding to the point of minimum aerial resistance. Comparative figures for a few Post Office aerials using buried-plate earth systems are as follows:—

Station	Minimum Resistance	Wave-length of Minimum Resistance	Radiation Efficiency
	ohms	m	per cent
Stonehaven (large) . .	1·40	5 550	24
Stonehaven (small) . .	3·75	1 800	60
Caister	6·25	800	40
Devizes	4·5	2 750	30

From these figures it would appear that the results obtained from an aerial and earth are as good as those obtained by the author. In none of the cases quoted above has an investigation been made of the losses occurring. If aerial and earth systems were suitably designed and dielectric losses reduced to a minimum, I am of the opinion that there would be very little to choose between a buried earth and an earth screen. With regard to eddy-current losses in the earth, I have made a few tests using a 2-wire screen and varying the

distance between the two wires. Comparative results are given below and these corroborate the author's remarks.

Distance between Wires ft.	Mean Resistance ohms
12	10
30	8
66	6

L aerial 70 ft. high, 150 ft. long. Screen; 2 wires, 250 ft. long, 6 ft. high.

Heavy dielectric losses have been noticed in wood. A screen was lead into a wooden hut through a small ebonite insulator; by leading in through a large porcelain insulator a reduction in resistance of as much as 4 ohms was obtained. The author's reference to screen oscillations is extremely interesting. In the course of experimental work these have been detected on several occasions: first with the 2-wire screen previously referred to, and again when using the same aerial and trying the effect of commoning the screen and earth system. Lastly, when using an L aerial 120 ft. high and a screen of 10 wires 12 ft. apart, the addition of an extra wire on one side of the screen set up screen oscillations, the resistance being 10, 18 and 5 ohms at 450, 600, and 900 metres respectively.

Professor C. L. Fortescue: The resistance of earth connections has for long been a controversial subject amongst wireless engineers. The results given in the paper—upon the accuracy of which little doubt can be cast—prove that the advocates of the extensive earthing arrangements were right. Earth screens closely resembling those described here, but having the outer edges connected to buried earth plates, have been used since 1906 and it would be interesting to know whether the author made any measurements with the outer edges of his screens earthed and, if so, with what results. When the outer edges are earthed, the resistance of the earth connection can be calculated from the ordinary formula for the distribution of a high-frequency current over a flat, conducting surface. With the generally accepted value for the conductivity of the moist earth the calculated results are in fair agreement with practical observation. This method of calculation gives an earth resistance inversely proportional to the square root of the wave-length. Some of the curves given in the paper show, apparently, that this is not exactly true in the case of the earth screen. The author's views as to whether this lack of agreement is due to dielectric loss in the capacity-earth connection of the insulated screen, or to some appreciable proportion of the surface current being a capacity current instead of a conductor current, would be of great value.

Mr. H. J. Round: If I might refer to the remarks of Mr. Warren, I am afraid he cannot have it both ways. He mentions that the resistance of the Post Office aerial at Leafield is 0·9 ohm, and compares it favourably with Clifden; I have heard, however, that the aerial current is 170 amperes, which gives approximately 27 kW in the aerial, and I understand that a 250-kW arc is in use. With regard to the question of the Lodge aerial, I quite agree with Major Erskine-Murray that this is in some respects a Lodge earth screen. There is no doubt that Lodge suggested this type, but we can go further back than that. The first counterpoise was undoubtedly used by Hertz, and throughout the progress of the art this suggestion of some form of capacity counterpoise instead of an actual earth connection has been introduced. My own association with the earth screen occurred somewhere in 1909. Mr. Marconi asked me to investigate the influence on the damping of an aerial system while bending an antenna from a vertical to a horizontal position, as he had noticed some rather peculiar results on the current in his aerial with a plain-aerial spark. I carried out some tests at Broomfield, and during these tests wires were laid under a very exaggerated type of horizontal aerial which was 5 ft. high and about 200 ft. long. It was found that the resistance of the aerial decreased as some function of the number of wires on the ground under the aerial. The more wires laid, the lower was the resistance; about 20 wires were put down. More or less by accident, I lifted the wires from the ground and removed the earth connection and in this way, with the same applied voltages from the spark circuit, got a very much greater current in the system. I reported these facts to Mr. Marconi and we discussed the question. At the time we were not quite sure of our ground with regard to radiation, and the fear was that we were going to reduce radiation although we had increased the current. These fears can, I think, now be removed because actually in some of the author's earth-screen experiments a test was made by measuring signals from an earthed aerial and alternatively from an aerial with a screen with the same number of amperes in the aerial, in each case taking no account of the power. At a distance of two or three miles, no difference whatever in signals could be detected. That measurement was repeated later on and there seems no doubt that the radiation resistance is the same with the earth or with the earth screen. After those first experiments in 1909 a mass of earthed wires was laid down at Clifden connected to the circular plate earth and run to the end of the aerial and beyond. That resulted in about 10 per cent increase in the aerial current. The war period interrupted further work. This subject of the radiation efficiency occurred to me as a suitable problem to tackle in 1919 and, fortunately, I was able to get the author to take up the subject. After 8 months of very intense work on his part we found ourselves, in the end, with an aerial system greatly increased in efficiency and much more amenable to calculation. A much greater problem is really arising. Reducing the aerial resistance still leaves us with the fact that with the same aerial we cannot get any more current into the aerial owing to the voltage limits, and really all that this increased efficiency has done is to reduce the power which we can put in. As generators have been devised to suit the old aerials, what are we going to do with the old generators? Before this work of the author, there was the classical work of Alexanderson on multiple feeders, which will always stand out, I think, as a very great aid to efficiency. The feeder system will be valuable in all sorts of cases, and there are many instances where it will be quite impossible to put up an aerial screen. More recently other people have been investigating this question of earth resistance, in particular Mr. Alexanderson and

Dr. Meissner of the Gesellschaft für drahtlose Telegraphie and, although I am afraid I cannot give any exact details, it really comes to this, that those investigators have developed an earthing system which is apparently about as good as the counterpoise, so that there is not very much in it one way or the other. The main thing in the earth screen is the ease with which the magnetic eddy currents in the ground can be balanced by a system of wires which must extend beyond the aerial in every direction to be really efficient, and the electrical effects on the ground balanced by an opposite potential on the screen. Every radio engineer will, in future, use each method in its right place, but I think that what this paper has done is to show up how to predetermine with some degree of accuracy the resistance of an aerial. There are one or two points in the paper to which I should like to have referred; for instance, there is the question of the method of measurement. Mr. L. B. Turner brought to my notice the fact that the method of slide-back contains an error of which we did not know; but a hurried investigation during the last week has shown that this error is not very great. In all our results it does not exceed 5 per cent in any single measurement and, actually, more or less by accident, it has cancelled out in the author's measurements.

Captain P. P. Eckersley: I think that many speakers in the discussion have confused a balancing capacity earth with a true earth screen. I used a Lodge aerial in 1908 more because I was told that this was a good method than because I had any idea that it actually screened the earth; furthermore, none of the protagonists of the balancing capacity ever brought this point of view to my notice. It has been left to the author to show us exactly the action of a true "earth screen" and he has analysed the losses occurring in aerial systems so that he can predict a given aerial performance with great accuracy, surely a great advance on past methods. I am very interested in the paper because I have had some little experience with earth screens for small power stations, particularly the Croydon Aerodrome ground station, which was erected with a screened aerial. The original design work was done at Writtle and the results with a screen designed by the author were extremely good. It was, therefore, rather disappointing to find that the aerial erected at Croydon had a resistance almost double that of the nearly identical Writtle aerial. The only difference in construction of the two aerials was that the Croydon aerial was asymmetrical to the hut and that the masts at Croydon consisted of steel lattice towers, while ordinary 70-ft. masts built of steel sections were used at Writtle. I imitated the Croydon aerial as regards asymmetry at Writtle and the results showed that, although the effective capacity of the aerial was changed, the resistance of the aerial was practically unchanged, showing that the high resistance was not due to asymmetry. It is probable that the site at Croydon, surrounded as it is by iron-roofed hangars, overhead mains, etc., was more responsible for the extra losses than anything else, showing, now that the screened aerial is being used, how much more sensitive it is to external conditions which, with the old earthed system, could be safely neglected.

Mr. F. C. Lunnon: The question of the effective height of an aerial is of considerable importance. Lieutenant Cobbold has pointed out that the analysis of the losses depends on a knowledge of the loss due to radiation. Some recent work at Chelmsford has shown that the effective height can vary from the calculated effective height more than was formerly supposed. I will give one or two figures to show what the difference can be. In the case of a single-wire **T** aerial supported on wooden masts with rope sets and rope halyards, the calculated value was 9·46 metres and the measured value 8·3, a difference of 12 per cent. A similar aerial supported on steel masts with wire sets and wire halyards had a calculated value of 16·1 metres and a measured value of 14, a difference of 13 per cent. Since the loss due to radiation is usually small compared with the total losses, any errors introduced into the estimate of the dead losses due to errors in calculating the effective height will be small.

Mr. E. H. Shaughnessy: Previous speakers have drawn attention to the Lodge aerial, but I find that the patent for the counterpoise, No. 11 271 of 1907, was taken out in Dr. A. Muirhead's name. Everybody has said that it was well known long ago. I should like to say a word of appreciation to the Marconi Company for instituting regular experiments to find out something definite about the subject. From the wireless point of view, they applied their results to Clifden and produced very marked improvements on high-power aerials—a very important matter. There is another point to which I should like to draw attention. On page 581 the author says: "Except for the pioneer work of Alexanderson with multiple, earthed aerials, not much progress had, until then, been made in the improvement of the efficiencies of wireless circuits and aerials." There the Marconi Company is giving very great credit to Alexanderson, but I find in an old patent taken out by Mr. Marconi in 1905 the following particulars of his **L** antenna: "Preferably the transmitting and receiving antennæ above described are completely insulated except for the connections at their generator and detector ends." It does not stop there. It goes on: "But they may be connected to earth at their tail ends or at other points, and inductances and condensers may be inserted in these earth connections." There is the Alexanderson aerial disclosed in a Marconi patent 14 788 of 1905. The Marconi Company apparently knew all about it, just the same as everybody here knew all about the Muirhead patent, but they gave Alexanderson the credit of having developed it and called it his pioneer work. I think we might give credit to the author and the Marconi Company for their pioneer work on this particular and important subject.

Mr. G. M. Wright: There is one point in connection with the practical working of very low-resistance aerials which I think is worth mentioning. I refer to the difficulty of signalling at high speeds. Suppose we have a transmitter of a given power; since the power in the aerial is E^2/R, as R is reduced, E must also fall, in order to maintain the ratio constant. A reduction in the applied electromotive force means that the current will grow more slowly. This produces a general round-

ing of the signals, owing to the fact that above certain speeds the dot is not of sufficient duration to permit the aerial current to attain its full value. The result is that if we take, say, the letter V, the effective amplitude of the dots is dependent on the speed of signalling. This effect is of great importance, as may be seen from the fact that, when the current in an aerial of about 1 ohm resistance, on a wave of 15 000 metres, is keyed at 100 words a minute the dots bear a very obviously incorrect ratio to the dashes. They are much too light at the receiving station. This suggests that, in order to get over the difficulty, some method will have to be devised of artificially increasing the power of the transmitter at the moment when the key is pressed, and at the same time applying an opposing voltage when the key is raised, in order to curb the signals.

Professor G. W. O. Howe: From the earliest days of wireless telegraphy, there have been those, notably Sir Oliver Lodge, who have supported the claims of the insulated counterpoise against those of the earthed antenna. In his Royal Society paper in 1907 Sir Oliver said: "The present trouble is caused by the utilization of the earth as one terminal of the aerial system both in sender and receiver. I do not expect this to be immediately admitted, but so it is—at any rate at land stations. . . . It is better to ignore the earth and work independently of it both at the sending and receiving end, taking care to keep everything insulated." Many stations have been built with insulated counterpoises, notably Sayville and Karlsborg, the counterpoise at the latter station consisting of 250 miles of 1-mm wire carried on 500 telegraph poles. The paper to which we have listened to-night represents the first scientific investigation into the theory and correct design of the counterpoise, and the author is to be congratulated on having brought to a successful conclusion such a masterly attack on the problem. There are one or two points in the paper to which I should like to refer. The Marconi bent antenna is usually credited with some degree of directive transmission, and the only satisfactory theory of this phenomenon is that of Hoerschelmann, according to which it is due to currents in the earth under and around the antenna. The interesting question arises: Has this directive property vanished now that the screen has largely eliminated these earth currents? If so, has not this type of aerial lost the only excuse for its existence? A symmetrical T aerial would have a higher efficiency. The counterpoise is not the only direction in which attempts are being made to improve the aerial efficiency. Mr. Round has already referred to the new earth system being introduced at Nauen. This was recently described at the Jena Congress by Meissner, who stated that they expected to increase the efficiency from $7\frac{1}{2}$ to about 50 per cent. These figures are based on tests made on small aerials. The system is apparently that described by Dr. Goldschmidt in his German Patents 299 766, 305 043 and 305 044 of 1917, and by Latour in his French Patent 493 063 of 1917. A large number of suitably distributed small earth connections, e.g. mere metal stakes driven into the ground, are connected together and to the transmitter by means of overhead wires. The author does not like the term "power factor," but regards the ratio of the energy lost per period of the oscillation to the energy stored in the condenser as something more fundamental. I fail to see how the definition of a ratio can be any more fundamental than the name by which the ratio is known, or how results derived therefrom can appear any less arbitrary. In the familiar vector diagram with its right-angled triangle it is immaterial whether one assumes the constancy of ϕ, $\sin\phi$, $\cos\phi$, or $\tan\phi$: the result will be the same and equally arbitrary. With regard to the question of nomenclature, the author has added a new one to the list of names by which his "earth screen" had previously been known; Lodge usually referred to it as the "lower aerial" or "lower capacity area," whilst most people called it "a counterpoise."

Mr. T. L. Eckersley (*in reply, communicated*): Major Erskine-Murray has taken me to task for neglecting former workers on the subject, especially Lodge and True. Now, Lodge undoubtedly showed that the resistance of his type of aerial, in which there was very little screening, was lower than that of an earthed aerial, but he did not give sufficient data for calculating how much lower; neither did he show how the losses occurred and what measures it should be necessary to take to reduce them, etc. The present paper aims at answering these questions, with what success the future alone can decide. It takes up the matter at a point where Lodge left off. In dealing with the question of the height of the earth screen I cannot agree with Lodge that the minimum capacity condition, for which by the way he gives no explanation, has any direct connection with the maximum radiation efficiency of the aerial. Experiments that we have made with different heights of screens, and the theory also, indicate that the conditions are much more complex than Lodge implies by his law. In general it is found that as long as the height of the screen is not more than 15 per cent of the height of the aerial, and so long as the spacing ratio, i.e. the distance between screen wires divided by the height of the screen wires, is maintained constant, and so long as the screen covers the same area, the resistance is nearly independent of the height of the screen. This is certainly approximately true of the eddy-current losses as is shown by the formula on page 588. The dielectric losses decrease as the screen is raised, since there is less leakage over the edge. The radiation for a given current remains practically constant, as experiments have proved. The best height for the screen therefore depends on the relative importance of these two factors, and cannot be reduced to any such simple rule as Lodge's condition. The practical point is this: a low screen requires more wires, but the cost of supporting masts increases rapidly with the height. A compromise must hence be made to suit existing conditions.

With regard to Fig. 1a to which Major Erskine-Murray takes so much objection, from the importance he appears to attach to what is merely a conventional drawing it might be inferred that he supposed I based my whole argument on the figure. Surely it is a matter of minor importance how an earth is indicated! Actually a

number of earths were used. The original one was a circle of zinc plates 20 ft. in diameter, each plate 3 ft. deep by 6 ft., forming a continuous circle. Insulated wires from each plate were brought to a post at the centre of the earth, and were then bunched and brought in by a short lead. This is by no means an ideal earth, but doubling the diameter of the circle made only a slight reduction in resistance, and again placing a large earth under the centre of the aerial so as to reduce the length of the earth returns currents also hardly reduced the resistance appreciably, so the figures with the original earth were allowed to stand. If Major Erskine-Murray requires a comparison of a buried wire earth with a screen, the case of Clifden may be cited. With this earth the resistance was about 4·5 ohms, while with the screen 0·6 to 0·7 ohm was the figure.

My diagrams seem to come in for a good deal of adverse criticism. Major Erskine-Murray takes objection to Fig. 4B. It is true that this resembles Maxwell's diagram, for the good reason that the distribution of lines of force given by Maxwell are approximately correct for the case where the upper capacity is a plate, as I have shown it for the purposes of convenience. The arrows on the central lines of force from the screen wire to earth have unfortunately got reversed (since corrected for the *Journal*). When the screen is insulated there should be as many lines going down on to the earth as leaving it. They all finally end on the screen. In this connection I am uncertain what should be considered to be the resistance of the aerial when earthed, in comparison with the screens. A series of wires buried in the earth running to the aerial constitutes a partial screen at least for the earth below them, and for this reason it is perhaps not fair to compare it with the fully screened aerial since it clearly constitutes one step in the road towards screening and the avoidance of earth-return currents.

The answer to the first part of Major Trench's remarks will be found in the reply to Major Erskine-Murray's questions, where details of the earths used are given. I am interested to hear that other workers have noticed the effect of asymmetry in developing spurious oscillations, with consequent losses. On page 583 of my paper I have stated that "Since there is necessarily a downward radiation from any aerial with horizontal wires the loss in the earth cannot be completely eliminated except when the earth is perfectly conducting or when there is a perfect reflection between the screen and earth." A series of wires laid on the earth as suggested by Major Trench is a step towards the interposition of a perfect reflector between the screen and earth, and it will therefore reduce the earth losses to some extent. To make a really effective screen, however, the wires would have to be so close together as to make an almost continuous sheet of copper. This is obviously impracticable, and I think that the improvement likely to accrue from any practical scheme is small. As regards the capacity of the screen, it must obviously be large compared with that of the aerial, and in general this is automatically provided for by making the screen overlap the aerial by an amount equal to the height of the aerial above the ground.

With regard to the reception with screened aerials, my experience is that the improvement in reception is just as marked as in transmission. I remember an occasion on which I used the screened aerial (circular type) at Chelmsford on a 900-metre wave. I was able to get the whole conversation between an aeroplane and Hounslow with a single Q valve, no amplification, when they were not able to keep in touch themselves.

In reply to Mr. J. E. Taylor, the aspect of the earth screen as a cage has been touched on in the paper, but this aspect is, I think, rather inadequate. In the first place, the screen is part of the aerial and not part of the box surrounding the aerial. For this reason the energy is not entirely confined within the space between the upper and lower capacities. As shown in Fig. 3, an isolated aerial and screen must necessarily radiate downwards (in the direction OP, Fig. 3), and no design of a screen which is part of the aerial can prevent this. The screened aerial does not entirely confine the radiation of energy to the horizontal plane. Mr. Taylor is to be congratulated on his early, clear recognition of the screening effect of such a counterpoise, as shown in his extract from notes compiled in February 1913, in all except the point referred to, i.e. the fact that the screening from the earth is only partial and not complete. Insulation troubles in continuous-wave work with the screen are not marked. On account of the large capacity of the screen the potentials on it are only of the order of one-tenth of the potentials on the aerials, and insulation becomes an easy matter. The only difficulty is in the number of insulating supports necessary in a large screen. These are all in parallel, and it is necessary to have good insulation on each in order that the insulation resistance of screen to earth may have a reasonably high value.

Lieut. Cobbold has touched on the one point on which a certain amount of doubt may exist—I mean the question of radiation. The radiation resistances given in the paper are all calculated, and these calculations are based on the assumption of a perfectly conducting earth. It is assumed that an earthed aerial will have this radiation resistance and that a screened aerial will have the same. This latter point has been checked experimentally. With a given current in an aerial 70 ft. high with an earth screen 7 ft. high the received signals at a distance of 2·9 km (signals actually measured by thermo-ammeter) are, as nearly as can be measured, exactly the same whether the direct earth or the screen is used.

The information given by Mr. Lunnon indicates the sort of error that may be made in assuming that the radiation resistance is that given by the formulæ appropriate to a perfectly conducting earth. A 10 to 13 per cent error may be made in the effective height, involving a 20 to 26 per cent error in estimating the radiation resistance. Actual values are always less than the calculated ones.

It will be well for me at this stage to disarm criticism with regard to the analysis of the losses by stating that the analysis is rather in the nature of a mathematical artifice. The analysis is not absolutely logically definite. An example will make this clearer than any amount of reasoning will do. If a closed surface is drawn round an isolated aerial and screen, the energy

radiated out through this surface is the same, for a given current in the aerial, whatever the surface may be, so long as it wholly encloses the radiating system. This energy in watts, divided by the square of the aerial current, is appropriately termed the radiation resistance, and there is no ambiguity involved. Now consider this system brought fairly close to the earth. Let us suppose that the closed surface (1) does not cut the earth and that the surface (2) does; some of the energy which gets through (1) is lost in the earth, and the energy which gets through (2) is reduced. If the surface cuts the earth, the energy which gets through the surface is not independent of the position of this surface and the radiation cannot be unambiguously defined. To be logically correct we should define the radiation energy as the energy which is radiated through any surface which cuts neither the aerial nor earth. To do so, however, would be to include in the useful work the energy radiated and lost in the earth just below the screen, a proceeding which appears to be grossly unfair. In my analysis I have included as earth loss all the energy lost in the earth below the screen on account of the currents produced there. This may be conveniently separated from the rest, since it varies very approximately as $1/\lambda^2$. As will be realized, the distance to which this loss extends beyond the confines of the aerial is a little ambiguous, and the radiation efficiency cannot be quite uniquely defined. For this reason I have avoided, except in one case, giving any explicit values of the radiation efficiency of the aerials with which I have worked. In the case of the original aerial the analysis of the dead losses given will not vary appreciably even if a large error is made in the radiation resistance, since this latter forms only a very small proportion of the total resistance. The results are, therefore, substantially correct, though it would be dangerous to attempt to calculate the radiation efficiency with any degree of accuracy.

The height of the earth screen is not critical; this point is dealt with more fully in my answer to Major Erskine-Murray's questions. As regards the overlap of the screen; this is designed chiefly to prevent dielectric loss which, in general, is important only on wave-lengths that are long as compared with the natural wave-length of the aerial. The overlap is therefore important only on these wave-lengths.

The improvement in Clifden signals on substituting a screen for the earth obviously depends partly on the method of reception. Perhaps it would have been wiser to make the less ambiguous statement that it required only one-sixth of the aerial power to produce the same R.M.S. aerial current with the screen as with the earth; the improvement in changing over from spark to continuous waves is over and above this.

I am glad to see that Major Lefroy confirms, as everyone else does, the main result that the earth screen gives lower resistances than the earthed aerial. With regard to reception, for a given strength of signal, E volts per cm, say, the current in the receiving aerial will only depend on (*a*) the effective height, (*b*) the resistance of the aerial; being in fact Eh/R, where h is the effective height. This has been abundantly proved in practice experimentally. Hence a given reduction in resistance will produce a commensurate increase in the received signal, so long as the effective height is the same. It has been proved that the screen lowers the resistance without lowering the effective height; the received signals on a screened aerial should thus be stronger than on an earthed one. This is only true if the detector circuit is so weakly coupled as to introduce very little, if any, extra resistance into the aerial circuit. If the detector circuit forms a major portion of the resistance of the aerial, then screening the aerial will produce either very little reduction in increase in signal strength or none at all. Perhaps Major Lefroy's experiments were done under these conditions.

Major Lefroy expresses some doubt as to whether an increased efficiency of the aerials produced an increase of range. Now, the range is definitely determined by: (*a*) the current in the aerial; (*b*), the effective height of the aerial; (*c*) the nature of the intervening ground, atmosphere, etc.; (*d*) the condition of the receiver. The effective height, however, is the same whether the aerial is earthed or screened. Hence the range only depends on the aerial current, (*c*), and (*d*). For the purpose of a comparison between the earthed and screened aerial, (*c*) and (*d*) should be considered constant. With a given aerial current the earthed and screened aerial will produce the same range, but the screened aerial will do so at the expense of very much less power. If the same input power is used there will be a greater current in the screened aerial and, consequently, a greater range will be obtained. The other factors, such as for instance the capacity of the screen to earth, do not enter immediately into the determination of the range, but only secondarily in as far as they affect the primary quantities, i.e. aerial current and effective height.

Strictly speaking, the symmetrical aerial Major Lefroy refers to should have no spurious screen oscillations. Everything depends on the slight degree of asymmetry which may exist. If, for instance, the aerial down-lead is not attached exactly at the centre of one of the screen wires an oscillation from end to end of this screen wire will be produced, since the point of attachment of the aerial and screen will not be at the node of potential of the end-to-end screen oscillation. The spokes of the screen should hence be made as nearly as possible all of the same length.

Mr. Warren gives the efficiencies of some of the Post Office earthed aerials in which the efficiency is greater than that in the example the author has given of a screened aerial. These efficiencies are obtained at wave-lengths where the resistance is a minimum. I doubt, however, if these wave-lengths are in any case nearly as great as $3\frac{1}{2}$ times the natural wave-length of the aerial, and it is this factor that counts. The radiation resistance varies inversely as the square of the wave-length; the earth losses inversely as the square root of the wave-length; and the dielectric losses directly as the wave-length. Hence the radiation resistance goes up much more rapidly with decreasing wave-length than do the other losses. It is possible to obtain quite high efficiencies near the natural period of the aerial even with earthed aerials. In fact with the aerial the

author has already quoted, at a wave-length equal to twice the natural wave-length of the aerial, the radiation efficiency appears to be nearly 75 per cent. Mr. Warren has not given us the figures from which he derives his efficiencies, and this makes it difficult to criticize. Taking his value 24 per cent for the large aerial at Stonehaven we can reverse the calculation as follows :—

The height of the Stonehaven aerial is 300 ft., roughly 90 metres. The effective height will not be more than 60 metres. Taking a working wave-length of about 5 500 metres, the radiation resistance is $1\ 600\ (60/5\ 500)^2 = 0{\cdot}19$ ohm. Hence the total resistance must be $0{\cdot}19/0{\cdot}24$, or about $0{\cdot}76$ ohm, which certainly seems less than would be expected.

The example of Leafield station which Mr. Warren quoted has set the author as well as Capt. Round wondering. A 250-kW arc such as Leafield possesses should be able to supply at least 100 kW to the aerial. With a resistance of $0{\cdot}9$ ohm an aerial current of 330 amperes should be obtained. Actually only about 170 A is obtained, representing about 26 kW in the aerial. What happens to the other 74 kW ? Either the power plant is largely in excess of what is required, or else there is some unexplained waste. It seems hardly possible that the voltage limit of the aerial was reached since, as I understand, larger currents are obtainable on longer waves.

The formula on page 587 is subject to criticism by Mr. Warren on the grounds that (*a*) the dimensions are incorrect, (*b*) it is obscure. With regard to (*a*) I can assure him that he is mistaken. The quantity ρ is resistivity in C.G.S., electromagnetic units ; h is in centimetres ; $p = 2\pi \times$ frequency. Let the dimensions of length be L ; of time, T. The dimensions of $1/h\,.\,(\rho p)^{\frac{1}{2}}$ are :—Resistivity $\rho =$ (resistance/length) $\times$ area, and since resistance $= L/T$, $\rho = L/T\,.\,L^2/L = L^2/T$.

Further, the dimensions of p are $1/T$. Hence the dimensions of $(\rho p)^{\frac{1}{2}} = L/T =$ dimensions of resistance. Therefore $1/h\,.\,(\rho p)^{\frac{1}{2}} = L/T\,.\,1/L =$ resistance per unit length, as stated.

As regards the obscurity of the formula, surely that is rather a curious term to apply. I have heard of incorrect formulæ but never of obscure ones. Mr. Warren should have no difficulty in calculating the resistance per unit length of a wire when the data are given, unless he is unable to perform the difficult and obscure task of deciding whether to take the positive or negative square root in the formulæ.

In connection with the aerials designed by Mr. H. A. Madge who earthed his screen at the end, Prof. Fortescue wishes to know whether the author has made experiments with the screen wires similarly earthed. I may say that experiments of this nature were made, but the earths at the end were not very good and the results discouraged the author from pursuing the matter any further. The earth and screen system has a node of potential a little way along the loading coil from its point of attachment to the screen. If the system is earthed at the node no change of resistance is noted. The further away from this point the earth is attached, the greater the earth currents, and consequently the earth losses. It was actually found experimentally that the resistance increased in proportion to the distance of the point of attachment of the earth from the node, at any rate for small distances. It was hence concluded that earthing at the end would seriously increase the losses. Of course, earthing at the end alters the natural mode of vibration of the system, in fact, forcing the end of the screen to be a node of potential, but it seems to me it can only do so on account of the earth currents carried by the earthing system at the end of the screen. The losses due to these currents are over and above the eddy-current losses induced by the wires of the screen in the earth, losses which are not eliminated by earthing in this manner. The method of earthing at the end has also the disadvantage that the loading coil and any gear connected with it are at a relatively high potential, and that the field of these is unshielded and may consequently produce large dielectric losses in the neighbourhood of the buildings.

I do not think that Prof. Fortescue's alternative way of regarding the eddy-current losses is quite adequate. It is not only a matter of spreading out the earth return currents as suggested by him. If an aerial and screen properly designed has a resistance R, then if the earth-screen network were buried in the ground some feet below the surface, the resistance of the system would be considerably greater than R, in spite of the fact that the currents are equally spaced out in both cases. The properly screened aerial has a lower resistance on account of a real screening effect, i.e. the differential action of the magnetic effects of the aerial and screen.

If the quantity $h(4\pi p/\rho)^{\frac{1}{2}}$ is greater than about 5 then the loss varies very approximately as the square root of the frequency. For the lower frequencies the loss falls off more rapidly than the square root of the frequency. The exact formula is in this case a good deal more complex, and the author is at present engaged in finding suitable approximations to it. The whole loss, apart from accidental loss in bad dielectric and wire resistances, has been divided into two portions, one varying approximately as $1/\lambda^{\frac{1}{2}}$, and one as $1/\lambda$. Whether this latter loss is, as I have assumed it, a dielectric loss in the surface vegetation, or whether part is in the earth and due to capacity current, I cannot definitely say, but I am inclined to the view that it is practically all surface loss for the following reasons : (1) Because it varies in proportion to the mean-square electric force and not in proportion to the mean-square horizontal force ; (2) the earth conductivity (in cases which I have dealt with) is so high that the capacity currents form only a very small fraction of the total currents in the earth, and I am inclined to think that these would be insufficient to cause any marked dielectric losses.

Captain P. P. Eckersley cites the case of the Croydon aerial, on a 900-metre wave, which did not give results nearly so good as an exactly similar aerial at Writtle. The aerial at Croydon was perhaps unfortunately situated, surrounded as it was by enormous iron hangars. The losses in these must be very considerable. It seems difficult to account for the increase of resistance otherwise than by losses such as this. The ground, however, may have been of higher resistivity, and I believe carried many buried cables, all of which would tend to increase losses. There was no sign that the increased

resistance was due to any spurious oscillations, as the resistance/wave-length curve was quite regular.

Mr. Shaughnessy seems to have appreciated the spirit in which the experiments described in the paper were undertaken. This paper is not a piece of special pleading claiming priority for the Marconi Company in the matter of earth screens—as other critics seem to have considered it—but is an account of a series of experiments carried out with the object of finding out something definite about it, an investigation which, so far as the author is aware, has not previously been made.

Mr. Wright has referred to the difficulty of signalling at high speeds with a low-resistance aerial, and his remarks show that it is not low resistance that we are seeking for, but rather that the low resistance aimed at is an unfortunate necessity of long-wave working, where the radiation resistance is necessarily a small quantity. This rather disposes of the peculiar virtue in Mr. Warren's measurement of the efficiency at the minimum resistance point. This point has no theoretical or practical importance.

As Prof. Howe suggests, the directive effect of an L aerial, which in any case is a very small amount, is almost entirely destroyed when the earth screen is used. In all practical cases the loss in directional radiation is small, less than 5 per cent, say. This is estimated on Hoerschelmann's theory. Of course it is obvious that the screened T aerial with a central connection has much less resistance than the same aerial used as an inverted L. But the T aerial has rather alarmed us so far on account of the ease with which an end-to-end oscillation of the screen is produced if the down-lead is not exactly at the electrical centre of the screen.

Meissner's method seems to be a compromise between the screen and ordinary earth. So far as I am aware he produces a distribution of currents in his earth by means of suitable chokes in the various leads, which the screen does automatically. I am also inclined to think that his method of earthing does not shield the surface dielectric loss and that, consequently, the screened aerial will have a lower resistance than any aerial of his type.

DISCUSSION ON

"TELEPHONE LINE WORK IN THE UNITED STATES."*

Scottish Centre, at Edinburgh, 14 March, 1922.

Mr. J. M. M. Munro: What surprised me most in the paper was the reported ease with which the multiple cables were pulled through the wire loops called "rings" hung from the steel strand for supporting the cables. The absence of wear, also of electrolytic action between the cable and rings, was also contrary to expectation. Has no trouble arisen from the effect of daily and seasonal temperature differences on the lead-alloy cable sheath? Lead is so inelastic that it may not recover from any considerable expansion, but the effects of the expansions may accumulate until it wrinkles, crystallizes and cracks. The smaller sketch of the Blackburn ring (Fig. 10) does not appear to agree with the larger one. For carrying and melting paraffin wax 10 feet from the manhole, dry weather would be welcome. At the startling working speeds described there does not appear to be much time for thermometric measurements of wax temperature, and very little for observing if the jointer is in a safe position before lowering the covered paraffin pot for boiling out. What average proportion of length of pairs of wires is idle due to spares and interchanging arrangements, equated over, say, a 10-year period? When a sleeve is bored for filling, is there not frequent trouble due to the borings or melted drops getting inside the sleeve? The expression "pressure testing" as applied to telephone cables should be "air-pressure testing." A little further information to supplement that given on page 105 might be vouchsafed regarding the "small conduits" or "suitable mouldings" used for carrying wires up to telephone instruments. A fair drawing of terminal boxes of types No. 8 and No. 14 would be useful; also some particulars of construction and connections of loading coils if they have any special features. If a high-tension power wire can be safely run on telephone poles it would solve some problems of outlying service, but something better than a break on cable sheaths would be required for safety. Mr. C. Vernier, speaking of mechanical excavators, says that in Britain they are unsuitable even to narrow rural roads because there the trenches are dug in grass margins close to hedge and fence lines. This is done usually for ease of digging, though with excavators the difference in this respect would not be great and one is enabled to get the cable a little further away from growing root tips. At the stub cables, are the pairs looped into and out of the stub wire, or merely spurred? The high insulation test required in Britain on completed cables may not be necessary to maintain, but it is a useful measure of the care taken in design and erection. I have not noticed that recent exhaustive research has

* Paper by Mr. E. S. Byng (see pages 85, 262 and 362).

been undertaken into the conditions affecting the corrosion of, and electrolytic action upon, lead and lead-alloy sheaths. The subject affects many cables and wires besides those used for telephony.

Mr. R. Waring: Some years ago I was particularly interested in the question of development studies. In the London discussion on this paper one speaker stated that the methods of carrying out the development studies in this country were based almost entirely on American methods. Whilst this is undoubtedly the case, it would appear that American engineers now go to a greater refinement than is usually considered necessary in this country. For example, at the bottom of page 87 it is stated that statistics regarding school enrolments, birth rates and death rates are taken into account. It is further stated that forecasts of telephone growth are made in relation to families rather than to population, as they are considered to afford a more reliable standard. In this country reliance has been placed on the class of property, i.e. whether offices, shops, warehouses or works, and, in the case of residences, the character of the district and the rental value of the property. Past growth and the ratio of subscribers to population are considered to be very useful checks on the development forecast. There would, I imagine, be considerable difficulty in ascertaining the number of families in houses in this country, but the conditions may be different in America. With regard to underground work, the author states on page 103 that electric lamps in conjunction with portable accumulators are used for the illumination of manholes. I should like to know whether this refers to town or country. In some of the more important manholes we have permanent lighting fixtures connected with the battery at the nearest exchange. One pair is taken out of a cable to one side of a wall plug, the other side of the latter being earthed. The pair is connected to the main 22- or 40-volt battery, as the case may be, through a suitable fuse. The jointers have a plug and metal-filament hand lamp. Normally the pair is disconnected at the exchange, the fuse being inserted at the jointer's request. The fitting used in the manhole is of a waterproof type. Portable accumulators have not been used in the West of Scotland for illuminating manholes. The wear and tear on accumulators of this description, where they have been used for other purposes, has been found to be very considerable, and the cost of transport has militated against their adoption. The matter is, however, under consideration, and any information that the author may have as to the type of accumulators, the facilities for charging, and the weight and capacity of the accumulators used for manhole lighting in America, would be helpful. With regard to the designation of wire, I find that it is sometimes described as B.W.G. and sometimes as N.B.S. For example, on page 91 it is stated that for toll lines a No. 8 B.W.G. (435 lb.) or a No. 12 N.B.S. (173 lb.) hard-drawn copper wire is used. Further on, reference is made to a No. 14 B.W.G. (96 lb.) galvanized iron and a No. 14 N.B.S. (102 lb.) copper wire. This nomenclature must give rise to confusion, and perhaps the author can say why these different standards are used. The statement on page 91 that glass insulators are now the standard for all purposes appears to have evoked some surprise in this country. It was shown in Culley's "Handbook of Practical Telephony" (5th edn.), published as long ago as 1871, that glass insulators were then tried in this country and found wanting. It may be that improvements in manufacture have altered the position, and perhaps the author could throw some light on this aspect of the case. Reference is made on page 92 to the transposition system, and it is stated that two methods have been worked out, one for exposed and one for unexposed lines. Generally speaking, it is the unexposed lines with which we are most concerned in this country. The Post Office system involves the use of terminations and cross-over wires at each transposition point. I gather from the author's remarks and from Figs. 6 and 7, that the wires are not terminated at these points in America, but the twist or revolution of the 2 or 4 wires takes place on a selected pole, this being effected by means of double-grooved insulators or ordinary insulators on special brackets. Perhaps the author will say whether the double-grooved insulator has any special features in addition to the double grooves. If this is not so it would appear that two separate wires are carried on one insulator, which I should not consider to be good practice.

Mr. J. D. Taylor: American practice differs but little from the practice in this country, so far as broad principles are concerned, but there are considerable differences in details which I should like to point out.

Publicity.—The American approaches the subject of telephony in a striking way; for example, he has apparently found it necessary to inform the users of the telephone and the general public what the telephone service really is, and on what it rests. He advertises his wares, so to speak, and in doing so adopts artistic and attractive methods (see the three advertisements headed "Vigilance," "Democracy," and "Economical Equipment" in the *Scientific American* for November and December, 1921, and January, 1922, respectively). He clearly prefers to inform the public rather than leave the public to inform itself.

Unity of control and organization.—The author states that the Bell Telephone System controls 12 600 000 telephone stations in America; and that there are only 900 000 stations outside the Bell system. He makes it quite clear in Section II that the Bell system is directed by the A.T. & T. Co., assisted by the Western Electric Co. It is interesting to observe that American engineers agree in actual practice that one control is essential for an efficient telephone service. This is the view which was held and expressed many years ago by the British Parliament. It is evident that the A.T. & T. Co. and the Western Electric Co. explore the entire telephone field in America in the widest sense; they design, experiment, test, and co-ordinate, and their activities cover both the engineering and commercial sides. I have drawn special attention to this phase of the telephone industry in America, because at one time the view was held on this side of the Atlantic that America was telephoned by a large number of different companies; whereas it is plain that in actual practice one administration controls practically all

telephony in America. There is another item under the head of organization which justifies special mention. Specifications for exchange equipment; development studies; long lines (both study for and provision of); research; manufacture and tests of stores; and other special works, are attended to by the Headquarters Staff of the A.T. & T. Co. or the Western Electric Co. The associated companies therefore exist to provide the capital, introduce local interest, and bring into use plant designed by the Bell system, to join up new subscribers, to maintain plant, and to collect revenue.

Long lines department.—So far as maintenance and revenue collecting and similar local duties are concerned, one can understand how an associated company can be responsible for all local lines, whether for subscriber to exchange or for exchange to exchange circuits within its area. But it is not at all clear how the Long Line Department functions without interfering with the associated companies, as it is an entirely separate Department, and provides and controls all long circuits, many of which must pass through the areas of several associated companies. It would be interesting to know in the case of a long circuit passing through several associated companies' areas (1) how the first cost of the long circuit, (2) the annual cost of the maintenance of the long circuit, and (3) the revenue produced by the long circuit, are divided between the Long Line Department and the associated companies concerned.

Specialists.—I presume the specialists on planning to meet development, on the adoption of and bringing into use new ideas, on cost studies, and on efficiency comparisons are on the headquarters staff and entirely free from routine work.

Development.—What useful purpose does the total number of non-subscribers serve? In one area the ratio of subscribers to non-subscribers may be 1 : 10, while in another it may be 1 : 100, and yet each area may be fully telephoned. The essentials are, I think, the number of existing subscribers and the estimated number of prospective subscribers.

Jointing: lead sheaths.—I should like the author to give a little more information about red paper and its use in connection with lead–antimony alloy sheaths. Does the plumbing of lead–antimony alloy sheath call for special treatment as compared with lead–tin alloy sheath?

Teeing.—The same wires are brought out at two or more points, that is, they are "teed." This is a useful practice, but one that can easily be carried too far.

Cable lay-out.—I think that the author does not intend Fig. 2 to be taken too literally, but that it should be regarded rather as an illustration. It indicates the provision of an excess of copper wire which could easily be avoided.

Poles.—Why are 7 classes of poles necessary, and why is circumference preferred to diameter? The latter is more useful, I think, than circumference, in conveying size and space occupied.

Conservation of timber.—It is said that where the site of erection of poles is remote from a forest or pole yard or store, creosoting is regarded as a measure of economy. From this one assumes that where there is much timber it is not worth while to preserve the poles. I think it is of national importance to make the timber supply last as long as possible, and that unless transport and other costs are entirely prohibitive all poles should be "preserved."

Wayleaves.—The lump-sum payment is interesting, but in this country the view is gaining ground that wayleaves required for public utility services should be free, or subject to a payment representing the loss or inconvenience to the owner—and no more.

Spacing of poles and insulation.—Poles in America are fixed only 33 to 50 yards apart. The insulation of long lines in this country with 60-yard spans is occasionally difficult to maintain. With 30-yard spans on coast lines subject to sea spray, the difficulty would be serious.

Arms.—It must be difficult for maintenance men on 10-wire arms to attend to the outside wires, which are 4 ft. 8 in. from the centre of the pole. Is the American supporting bracket for the long arm as good as the arm combiner used in this country?

Pole brackets.—In a country where wood is so cheap and plentiful, I should have thought that a 6- or 8-wire arm at the outset would have been more economical than several brackets fitted now and then. In America is there nothing between a 10-wire arm and a bracket for one wire?

Glass versus porcelain insulators.—It would be useful to have some comparative figures of the insulation of porcelain and glass insulators under actual and similar working conditions in America.

100-lb. copper wire.—This has been proved over and over again in this country to be too weak mechanically, save in sheltered places. Its breaking point is 330 lb., while that of 150-lb. copper wire is 490 lb.

Joint use of poles.—What arrangements are made as regards maintenance and renewal of poles, which are used not only for telephones and telegraphs, but also for electrical power circuits? I consider the joint use of poles for telephone and electric power to be most undesirable and a method to be avoided as far as possible (see Mr. Bartholomew's remarks, page 114).

Sleeve and soldered joints in wires.—There are efficient observant maintenance men in this country who prefer a good soldered joint to the sleeve joint. The latter is very useful, however, in permitting a maintenance man to leave a fairly reliable joint instead of a dry, unsatisfactory one.

Electrose insulator.—It would have been of advantage if the holes in the electrose insulator through which the wires are to be threaded had been dotted in in the cross-section sketch.

Storm stay.—Is this a longitudinal stay to prevent the wires from running back when a section is broken? This leads one to suggest the need for a glossary of American telegraph and telephone terms.

Oscillation method of ascertaining dip or tension of wires.—This method has been in use in the British Post Office for years, but it was never as popular as the simple method of reading the tension from an indicator. It has been found useful to arrive at the length of span between two points, when actual measurement was not possible. A copy of the schedule used in America would be very useful.

Ring cuts and maintenance of aerial cables.—The phrase "for preventing ring cuts" on aerial cables is used in the paper. What exactly are "ring cuts" and are they common? A few words about the maintenance of aerial cables and on localizing and clearing faults on them would be welcome.

Crushing of cables by freezing of water.—I should be glad if the author would say what this is.

Coils fitted into cables for superimposing.—What is the practice in America in this connection? Are the coils fitted as required or is the cable equipped fully at the outset?

Carrier and other superimposed circuits where open wires are concerned.—Are all open wires required to carry as many superimposed circuits as possible, or are some open wires left normally without super-circuits so that they may be available for use in replacing other super-circuits which may be broken down by a fault on their "foundation" line.

Identifying marks.—Does American practice retain the (*a*) and (*b*) wires of a pair?

Provision against lightning.—What provision is made where open wires join aerial or other cables?

Party lines.—Are these lines encouraged in America as part of the standard telephone system which is required to give satisfactory service between *any* centres?

Speed of jointing lead-covered cables.—The author states that a 600-pair joint is often made in an 8-hour day by a jointer and mate. Does this include preparation work at the beginning, and clearing up at the end of the day?

Mr. A. S. Hampton: I desire to say a few words about the outside construction. The author speaks of the use of wooden pins for insulators, and it would be interesting to know something about the life of these pins, as experience in this country seems to indicate that wooden insulator pins are unsuitable. In the recent storm which occurred on the 15th January, 1922, hundreds of $\frac{5}{8}$-inch wrought-iron insulator bolts were bent and twisted into every conceivable shape by the storm. Construction work in America would seem to be done much more quickly than in this country. In the paper it is stated that poles are erected at the rate of 300 a day of 8 hours with 8 men, but no mention is made of how the poles are distributed nor how long it takes to lay them out. In addition, it is not clear whether the laying out is included in the erection of 300 a day. The use of tractors and boring machines must be of great advantage to American engineers, but I do not believe these machines would be of much use in this country, especially so far as railway work is concerned. The author speaks of these machines as being operated by 2 men but, from a number of the photographs exhibited, it was apparent that more than 2 men were required to operate the machine. Cable carriers are erected at the rate of 5 000 a day. Can the author say what effect the carrier has on the lead covering of the cable? Does he think it possible to erect similar lines in this country and, if so, how long does he think they would last, say, in Scotland?

Mr. R. Alexander *(communicated)*: There are several points in the paper on which I should like further information.

Stays.—It is stated that it is considered unnecessary to have turnbuckle, swivel or other device for adjusting tension, and that 3-bolt guy clamps are fixed very quickly with the aid of a small pair of blocks which pull up the wire to the required tension. Presumably the guy clamps serve for adjusting the tension, but if blocks and tackle have to be carried about for the purpose the arrangement seems neither convenient nor economical. The statement that "it is seldom found necessary to release any clamp subsequently for the purpose of tightening the wire" is open to doubt. The same forces which loosen stays in this country are operative in America (e.g. storms), and if they do not tighten their stays there must be a very large number of slack ones. It might be interesting to mention that in 1909 stay connectors, as they were then called, were experimented with in this country under the personal instruction of Mr. Moss, the inventor. One experiment was as follows:—

Four V stays were attached to H poles, 2 with Moss connectors, and 2 by the Departmental standard method.

1st V stay with Moss connectors: 62 minutes.
2nd V stay with Moss connectors: 40 minutes.
1st V stay standard method: 41 minutes.
2nd V stay standard method: 52 minutes.

The stays made by the standard method were rather more difficult, being on the hedge side. The Moss connector stays were tightened up by the foreman, and the time taken is not included in the figures. Tightening up is included in the standard method.

Glass insulators.—Apart from the question of insulating qualities, there seem to be two reasons for the use of glass insulators in the United States in preference to porcelain, (1) that porcelain is more expensive there than glass, and (2) that porcelain insulators, on account of their opaque character, may be more attractive nesting places for insects than transparent insulators. In the early days of the telegraph when, perhaps, high insulation was not a matter of such importance, glass was freely employed, but great improvements have taken place in the manufacture of porcelain insulators, increasing their insulating properties and reducing the price so that, at the present day, this material holds the field almost entirely in this country. Green glass insulators of French manufacture were experimented with in the North of Ireland some years ago, the comparison being with eburine and mixed porcelain. Three wires on the same poles were insulated with glass, eburine, and porcelain, respectively. The porcelain insulators were, to a great extent, of an old form with fixed spindles and, as a consequence, the insulation was lower than would have been the case with insulators of standard type. The length of each wire was about 25 miles and numerous insulation readings were taken. On the whole those for eburine came out slightly lower than those for glass, but better than for the mixed line of old form porcelain. Experiments elsewhere with eburine and standard porcelain showed that, though initially eburine was as good as porcelain, it was gene- ally lower and, with the insulators in a wet or damp

condition, the results were entirely in favour of the porcelain type. From these experiments it seemed fairly conclusive that porcelain is better than glass for the British Isles. We have no great trouble with insects; to a small extent spiders spin their webs between the insulator sheds, but it is not thought that any appreciable loss of insulation is due to this cause.

Wayleaves.—A lump-sum payment per pole rather than an annual rental per pole is an attractive idea, but has another payment to be made when property changes hands?

Pole holes.—Is much difficulty experienced in general situations in excavating a circular pole hole to a depth of 6 feet?

Concrete manholes.—Reference is made to the roof portion being reinforced. Is it to be understood from this that it has been found unnecessary to reinforce the sides?

Bonding.—This is done by means of tinned copper ribbon. Can the author say why lead sheet is not used?

Aerial cable.—To run a cable on a bend with the pull towards the pole, with a rope mat to prevent abrasion, does not seem to be very good practice. The conditions which necessitated this were probably exceptional. Perhaps the author will refer to this in his reply. Is nothing required to prevent the round-section steel suspension rings from cutting into the lead? The use of marline ties and grade clamps referred to later in the paper appears to indicate that the steel ring has this disadvantage. In Fig. 8 a reinforcing link is shown. This will no doubt take some of the stress off the clamp, but its design does not seem very good so far as the suspending wire is concerned. It seems to introduce two points where the wire would be subject to abrasion.

Mr. E. S. Byng (*in reply*): It is very gratifying to find that the discussion at this Centre opened up many questions of interest not mentioned at other Centres. Where, however, repetition has occurred members are requested to refer to my previous replies. In the following reply questions are dealt with in the order in which they were raised.

Mr. Munro inquired whether trouble had been experienced from the effect of changes in temperature upon the sheath of aerial cables. Except where the cable is on a gradient this effect is negligible. To prevent cable "creepage" as a result of changes of temperature, grade clamps are used to secure the cable to the suspension strand. The hooks in the smaller sketch of the "Blackburn" ring (Fig. 10) should have been shown on the opposite side of the strand, thus bringing them into conformity with the correct practice, which is illustrated in the larger sketch.

The kettles used for heating and carrying paraffin wax are fitted with lids; therefore the state of the weather does not enter seriously into the question of cable jointing. The helper heats the wax and has it ready at the moment required by the jointer, whose time is therefore not occupied with these subsidiary operations. Specific information regarding the average proportion of idle wires in individual cables was not obtained, but some reference to this question is made in my reply to Mr. Taylor. When a joint is to be filled with paraffin wax, as detailed on page 103, it is the usual practice to cut two small, circular holes in the lead sleeve before it is drawn over the joint; the lead sleeve is allowed to cool after being filled, and the holes are then sealed by means of two small discs of lead shaped to fill the holes and soldered into position. I agree that a clear distinction should be drawn between the air-pressure test as applied to telephone cables, and the term "pressure test" adopted for power cables.

One of Mr. Munro's questions related to the "small conduits" or "suitable mouldings" used in house-cabling systems for wiring between distribution boxes and subscribers' instruments. If the architects notify the telephone company in time to permit of the work being planned to the best advantage, concealed runs may be secured and circuitous routes avoided by embedding small conduits in the walls during building. An alternative method is to provide wide shell-moulding in corridors, and a smaller moulding in rooms, behind which wires can be accommodated. These mouldings serve as a continuous trough from each distribution box (which is often recessed into the wall near the ceiling) to every room served therefrom.

As mentioned on page 96, a drawing of the No. 14 type of cable terminal was furnished in a paper read by Mr. F. G. C. Baldwin before the Institution in 1909. No radical change has since been made in the external appearance of the terminal. A new design differing in certain essential features is now undergoing life tests, but details are not yet available. An account of the most recent research work undertaken by the American Committee on Electrolysis is given in its Report for 1921, which has just been issued by the American Institute of Electrical Engineers. The report describes very fully various tests for electrolysis, and methods of mitigating the trouble.

Mr. Waring drew attention to refinements made in the preparation of development studies. The number of families in an American city at the time of survey is ascertained by the field men, who make direct inquiries, and the figures for previous periods are obtainable from census data. The number of persons per family ranges from 3·5 to 6. Although the ratio of telephones per 100 of population is considered for certain purposes, it is not regarded as so suitable for development studies as a ratio in which the number of "families" is taken as the basis. It is conceivable that eventually there may be an average of one telephone per family, a stage which might be defined as the "saturation point." Experience has shown that the refinements detailed in American development studies are particularly helpful and enable a reasonably correct judgment to be formed as to the probable telephonic development. Although every possible care may be exercised, exceptional events sometimes occur to upset all telephone development calculations, as was exemplified some years ago by the sudden boom in the automobile and rubber businesses which affected the towns of Detroit and Akron in a manner which could not have been foreseen. In general, however, by dint of the methods adopted,

commercial engineers are able to obtain fairly close estimates of future growth.

In reply to Mr. Waring, who asked for information regarding the lighting of manholes by electric light, a portable outfit for jointers' use consists of a sheet-steel case, approximately 17 in. long, 6 in. wide, and 11 in. high, with a hinged cover and shoulder strap. The case is divided into two compartments, one for five small secondary cells, and the other for two 12-c.p. lamps and two 11-ft. cords. A flush receptacle is mounted in the front of the case for connecting up the lamp cords. The cells are of the Edison type, and have a total capacity of 37½ ampere-hours at 6 volts. The total weight of the complete outfit is approximately 40 lb. The use of these portable lighting sets is standard practice in the Eastern States. Since they are needed only in abnormally deep, dark manholes, or for night work, there is little occasion to use them in small towns, especially as overtime is generally avoided. Arrangements are made for regular delivery and return, by motor truck, of all portable sets from and to a central charging point. With reference to the nomenclature of wires, to which Mr. Waring drew attention, the gauge used in America for hard-drawn bare copper wire is the N.B.S. (New British Standard), except in the case of No. 8, which is B.W.G. (Birmingham Wire Gauge). All galvanized iron used for overhead conductors is measured in the B.W.G. gauge. The telephone companies have, however, recently adopted numbers which represent the diameters of open wires in thousandths of an inch (mils) and, in order to simplify the designation, the decimal point and the reference to inches are omitted. For example, a No. 12 N.B.S. hard-drawn copper wire would be known as 104 copper wire, and a No. 8 B.W.G. hard-drawn copper wire as 165 copper wire. No alteration is contemplated in regard to copper wire used for cable, which is measured in B. & S. (Brown & Sharpe) gauge. Mr. Waring's reference to early British experiments with glass insulators is interesting. I understand that experience in America was somewhat similar, and that the single-shed glass insulator, which was at one time used for long-distance lines, proved to be unsatisfactory. Trials with a double-shed porcelain insulator on long-distance circuits ultimately led American engineers to the conclusion that, with a second shed, glass insulators would prove entirely satisfactory. Experience and tests proved this assumption to be correct, and double-shed glass insulators have therefore been adopted as standard on high-grade toll circuits. In the American transposition system wires are not terminated at transposition points; Mr. Waring is correct in his statement that they are virtually rotated at selected points by the special arrangement adopted. The two-piece insulator, however, is not an ordinary double-groove insulator. There are two separate threads on the special 9-in. wooden pin, and the insulator consists of two distinct parts, which screw independently on to the pin. Consequently there is no direct connection between the two wires. For short-distance toll lines these two-piece insulators have proved satisfactory in every way. At phantom transposition points on short-distance lines, a one-point bracket is fitted [Fig. 6 (*b*)] and this enables a two-piece insulator to be used, in addition to the one carried by the pin on the arm. Thus the four wires required are accommodated. Three-point brackets [Fig. 6 (*c*)] are used only for high-grade toll circuits.

Mr. Taylor raised several interesting questions, to which, for the sake of convenience, I will reply under the same paragraph headings.

Publicity.—The popularity of the telephone in America is probably due largely to vigorous and systematic publicity. In order to bring home to the public the advantages of the telephone an advertising campaign on a very large scale has been sustained for many years, particularly by the A.T. & T. Co. and Associated Companies. This has undoubtedly had a most stimulating effect upon the growth of the demand for telephone service.

Long lines department.—The position which this Department occupies in the Bell system is very important as it operates practically as a separate and complete organization. When a new local duct route is being planned by an associated company, the Long Lines Department is consulted as to what provision, if any, should be made for long-distance cables for the ultimate planning period, in order that suitable provision may be made for the requirements of both the local company and the Long Lines Department. One or more ducts are then rented from the Associated Company and are available, when required, for long-distance cables. The Long Lines Department erects its own route at its own cost beyond the outskirts of a town; owns and operates the toll exchanges (also any repeater exchanges or apparatus *en route*) and the cables or open wire lines between them; and appoints and controls section linemen for maintenamce purposes. In the ordinary course circuits would not be rented from the associated companies, as their plant is designed upon a different basis and is generally unsuitable for long-distance lines. In some cases arrangements are made for the associated company to carry out construction work on behalf of the Long Lines Department. Were it not for these definite lines of demarcation and responsibility, it would not be possible to operate the transcontinental circuits, which pass through as many as 12 of the Federal States. The various Associated Companies are not, except indirectly, interested in these through-circuits, and they do not in any way control the composition of the lines or their equipment. These particulars should elucidate the position of the Long Lines Department in relation to the remainder of the Bell system.

Specialists.—Mr. Taylor's view is correct. The specialists are attached to headquarters and have no routine work to do.

Development.—Every non-subscriber is regarded as a potential subscriber. Therefore information regarding all non-subscribers including their valuation as "prospects," is scheduled when a development study is prepared. Notwithstanding the exceptionally high ratio of telephones to population in America, the commercial engineers there do not, I understand, regard any place as "fully telephoned."

Jointing: lead sheaths.—The method of plumbing cables is precisely the same whether antimony alloy, lead-tin alloy, or pure lead sheath is employed. It was explained on page 89 that cable with an antimony-alloy sheath has red paper over the core so that, when returned for scrap, it can be readily separated from tin-alloy sheath, the salvage value of which is considerably higher. This method of identification also furnishes, independently of records, a means of determining the nature of the alloy for engineering research purposes, in the event of unexpected physical faults developing. A further advantage of the red paper is the indication which it provides to the jointer that short pieces of scrap sheath must not be added to the metal pot if the heated metal contains too much tin.

Cable lay-out.—As mentioned in my reply on page 368, Fig. 2 should not be taken too literally, although it will generally be found that there is an excess of copper, in comparison with a diminishing or tapering cable system. The increased cost of the extra wires between adjacent manholes is counterbalanced by the advantages gained when diversions and alterations have to be made.

Poles.—The wide range afforded by the 7 classes of pole available assists engineers in selecting poles to suit local requirements. Pole circumference is considered by American engineers to be better than pole diameter as an index to the strength of the pole. Further, the circumference is very easily ascertained by passing a tape round the pole. At the yearly inspection the circumference of each pole is checked to serve as a partial indication whether replacement is necessary or not. If diameters were used they would have to be obtained by calculation from the circumference, or measured by callipers. In the latter case the reading might be quite inaccurate, as the diameter of a pole badly decayed at the ground line may vary considerably along different axes.

Arms.—Apparently the greater length of 10-wire arms does not present difficulties to linemen. The increased spacing of arms—24 inches—is probably of some assistance, as it makes the outside wires more accessible. Cross-arm braces of the American design possess the advantage that several wires may be run out simultaneously without unbolting the arm brace. The dimensions of the arm, as given in Fig. 3, are greater than those of the arm used in Great Britain. Consequently the American type of arm is somewhat stronger; and close observation on several routes reveals no tendency for arms to tilt. Where special strain is imposed on the arm, a 9-ft. back brace is also fitted.

Pole brackets.—These are used infrequently, except, as stated in the paper, where a maximum of only two or three circuits is contemplated for some years ahead, or when an emergency circuit is required. At one time a 6-pin arm was also in use, but the 10-pin arm is now standard in the Bell system. Since telephone wires in America are all run straight, only one arm is required for five circuits. If trees or other obstacles necessitate a shorter arm or side arms, the 10-pin arm would be cut down to the required length. This, however, is not of frequent occurrence.

100-*lb. wire.*—If it is necessary to use copper wire for a subscriber's overhead line it is generally found that, with the shorter span (120 to 130 ft.) adopted in America, 080 copper wire (102 lb.) has the required factor of safety. If the line is in a very exposed area, or if better transmission is essential, the next larger size of wire, namely, 104 copper wire (173 lb.) would no doubt be used. This has a breaking strain of approximately 550 lb.

Joint use.—Arrangements are made between the public utility companies concerned as to the responsibility for the construction and maintenance of joint-use plant. Thanks to the close co-operation which exists between the parties, no difficulty appears to be experienced in carrying out these arrangements. I am fully in accord with Mr. Taylor's views on the undesirability of joint-use poles under normal conditions. In order to avoid duplication of poles, however, the telephone companies have frequently been compelled by municipal regulations to combine their plant with that of the electric supply undertakings. Furthermore, in joint-line construction the amount of interference is controlled, which would not be the case if each of the two utility companies had its own route on a highway, and was possibly endeavouring to overbuild the other's route. As a result of the mutual arrangement, the two types of plant are erected to definite specification, and the amount of inductive disturbance is reduced to a minimum.

Electrose insulator.—I agree that in the cross-section of the electrose insulator (Fig. 5) it would have been better if the holes immediately below the metal inserts (through which the bare wires are passed) had been shown dotted to indicate more clearly the details of internal construction.

Storm stay.—The necessity for, and the purpose of, storm stays are explained in my reply to Mr. Jones (see page 369).

Oscillation tests.—In the paper I described only the oscillation test made in connection with the erection of suspension strand. During my visit to the United States I confirmed the advantages of this method over the dynamometer method of obtaining the correct tension. The oscillation test is also applied to the erection of open wires. Tables adjustable for type and size of wire, length of span and varying temperatures, are supplied to the linemen. Another method of obtaining the correct tension is by means of sag measurement. Two sag gauges are fitted on an arm at each end of the span. The gauge carries a target, which is moved up or down by means of a set-screw for sighting from one pole to another. A ready means of measuring the amount of sag is thus provided.

Ring cuts.—The first portion of Mr. Taylor's question on ring cuts is covered by my reply to Captain Carter (see page 122). At one time ring cuts were prevalent, but after careful observation remedial measures were suggested and adopted. The trouble has now to a large extent been overcome. In the maintenance of aerial cable the general principles are the same as in the case of underground cable, with one exception. As the sheath of an aerial cable is accessible throughout, the special testing set described by Mr. Adams (Fig. D)

can be used to locate the exact point of trouble. The probability that lengths of cable will require complete replacement on account of breakdown is less with aerial than with underground cable, more particularly in view of the feature mentioned in my reply under the sub-heading of "Annual Costs" (see page 371).

Crushing of cables by freezing of water.—During winter months, when the temperature in the Eastern States often falls several degrees below zero, there have been many failures on underground cable systems owing to water freezing in the pipe, more especially at the laterals to terminal poles. The expansion crushes the cable sheath and so leads to contacts and earths. These faults are usually of a permanent character and therefore involve the replacement of the cable. Where no spare pipe is available or if the spare pipe is also ice-clogged, it is customary to thaw out with steam passed through long lines of rubber hose equipped with a nozzle and fastened to steel rodding tape ("snake"). Steam is supplied by a small portable boiler working at about 150 lb. pressure. It was understood that sometimes, if the cable has not been very badly flattened, the faults disappear after the pressure has been released by the application of steam.

The risk of water accumulating in the ducts is guarded against by laying them at a suitable gradient and fitting lead caps to the cable sheath so as to form a shed at the top of the riser pipes of terminal or distributing poles. A further precaution taken in the territories affected is to inspect all external riser pipes once a year for rusting near the ground line.

Loading coils.—On grounds of economy large cable is not, as a rule, fully equipped at the outset with loading coils. It is, however, customary and regarded as good policy to load the phantom circuits when the component side-circuits are loaded for a given number of circuits. In Philadelphia I was impressed by the large amount of labour required on the road when inserting phantom circuit coils in cable circuits previously loaded on the side circuits only. The work of measuring cross-talk on each side, and selecting the right combinations (known as "poling") was incurred as a result of some war measure which had prevented the phantom and side-circuit coils being included at the outset. The selection for minimum cross-talk within the loading unit can be accomplished much more readily and accurately in a properly equipped laboratory than in the field.

Carrier circuits.—The general rule is that all circuits shall be so designed and constructed as to render superimposition possible. At the time of my visit only single pairs of wires were being used for carrier-current working. Methods of modifying the transposition of circuits were under consideration with a view to making one pair of each phantom group available for carrier-current working. In these circumstances the plan mentioned by Mr. Taylor would probably be followed, viz. that if one circuit used for the carrier current broke down, the service could be transferred to the companion pair, because the two side-circuits in the phantom group would be equally well balanced.

Identifying marks.—No means are provided for distinguishing the "a" and "b" wires in either subscribers' or toll cables. A temporary method of identifying the two wires of each pair during the installation of duplex cable is described on page 103 of the paper. With this exception the engineers have not found the marking to be necessary either during the construction or the maintenance of cables.

Provision against lightning.—Open wires are connected to a cable terminal by means of covered bridle wires which pass through lightning arrestors (copper blocks and mica separators). The arrestors are mounted in a galvanized iron box with cover (known as "61 Protector Mounting") containing groups of 10, one box being attached to each cross-arm. For most conditions the cable terminal is equipped with fuses, the near end of these being screwed into a mounting to which the paper-insulated cable wires are connected within a sealed chamber filled with compound. To the outer end of the fuses the bridle wires are connected.

Party lines.—Two-party and four-party lines are common in America and have tended to popularize the telephone, particularly among small householders. Now that 4-party lines are ordinarily equipped for harmonic or selective ringing, the subscribers suffer little inconvenience as a result of sharing a common line. In farming districts 20 or more subscribers are accommodated on one and the same line. The standard of transmission afforded is, however, such that long-distance working is possible to any part of the United States.

Speed of jointing.—Preliminary preparations and plumbing and closing down are included in the work of making a 600-pair joint, carried out by some jointers in a normal day. It should, however, be mentioned that this is not a performance accomplished or even attempted by all the associated companies. In some parts of America it is considered that a 400-pair, 10-lb. joint is a satisfactory day's work. In both cases only straight joints are concerned, additional time being necessary for testing or numbering through.

In reply to Mr. Hampton, I think it possible that wood pins would have stood up quite as well as $\frac{5}{8}$-inch wrought-iron insulator bolts during the snow-storm in this country, to which he referred. As mentioned on page 369, telegraph companies in America use steel bolts, but the wood pin is standard in the Bell system and is regarded as having a longer life. The labour involved in distributing poles along the line of route was not taken into consideration when the utility of the derrick-fitted motor truck was described in Section VII of the paper. In order to achieve the result described, poles are delivered at least one day before being required, and holes are excavated in advance. My reply on page 120 refers to this particular performance. Usually a trailer will carry about 35 small poles at each delivery. The photograph (shown as a lantern slide) of the pole-hole excavator, to which Mr. Hampton refers, was taken during a demonstration, when several engineers from the associated companies were present as spectators. Therefore it is incorrect to assume that they were in any way assisting the two men engaged on actually working the machine. Probably their presence had the opposite effect.

Reference has previously been made to the effect of cable rings upon the lead sheath. I think that the question whether it is possible to erect an aerial cable route in Scotland may be answered in the affirmative, provided that the pole route does not also carry a heavy bed of open wire lines. The mountains in Pennsylvania are about as rugged and difficult as anything which could be found in Great Britain. Experience has several times proved that while each individual wire on an open route will gather a large amount of snow and ice, the mass accumulating on the large circumference of the cable (which carries the equivalent of many circuits) will not be much more than that on one of the individual wires. It is this fact which renders open wire routes so liable to be brought down during winter storms, whereas in no single instance, so far as I am aware, has a route carrying only cable been wrecked. Without a full knowledge of local conditions it would not be safe to assert how the life of aerial cable, properly erected, would compare with that of underground cable. Underground cable is undoubtedly free from many of the hazards to which aerial cable is subjected; therefore each case must be considered on its merits.

The following replies relate to questions raised by Mr. Alexander:—

Stays.—I am not familiar with the Moss connector, but possibly the time element would be about the same as with the standard 3-bolt clamps. I cannot speak with personal knowledge about the frequency of tightening stay wires, but in various conversations I held with experienced engineers in America it appeared to be the general consensus of opinion that the absence of regulating facilities was no detriment to the maintenance of the plant. "Storm" stays require only a slight amount of tension; and in the case of reinforcing stays placed at points of strain the wire does not usually become slack unless the rods are drawn. If the stay rods are properly set this seldom occurs except during heavy sleet storms. At such times the presence of stay tighteners would not be of any advantage.

Glass insulators.—I have to thank Mr. Alexander for his interesting contribution on this subject, as it adds materially to the information available respecting the relative advantages of glass and porcelain.

Wayleaves.—This question is covered by my reply on page 368.

Pole holes.—No difficulty is experienced in excavating circular pole holes when long-handled and specially shaped bars, spoons and shovels are used. One man per hole is sufficient, and the work is completed more quickly than when a stepped, rectangular hole is made.

Concrete manholes.—In standard types of manhole which are less than 9 ft. in length, 6-inch concrete is used for the sides, and is not reinforced. Where the length is 9 ft. or over, either 6-inch reinforced or 8-inch non-reinforced concrete walls are constructed throughout.

Bonding.—The ribbon used for bonding cable sheaths in manholes to prevent electrolysis consists of soft, tinned copper strip, $\frac{3}{8}$ inch wide and 0·05 inch thick. Copper is considered to be much more durable than lead.

Aerial cable.—The position of aerial cable at angle poles is fully dealt with in my reply to Mr. Vernier (see page 370). The marline tie is intended to take the weight off the two metal rings on either side of the pole to which the suspension strand is rigidly clamped. Reinforcing links have been in use for some years, and the weakness suggested does not yet appear to have developed.

THE THIRTEENTH KELVIN LECTURE.

ELECTRICITY AND MATTER.

By Sir Ernest Rutherford, F.R.S.

(*Lecture delivered before* The Institution, 18*th May*, 1922.)

In my lecture this evening I shall endeavour to cover in a brief way a very large subject. I shall try in the short time at my disposal to give a review of the great advances made in recent years in our knowledge of the relations between electricity and matter. This will lead us almost at once into the fundamental problem of physics—the constitution of the atoms of the elements.

I believe it has been customary in the earlier Kelvin lectures to give an account of some phase of Kelvin's work. I could easily do so this evening by concentrating on the publications of Kelvin that deal with the proof of the atomic nature of matter, the dimensions of atoms and molecules, including the first suggestions of the mechanism of atomic constitution. This was a subject in which Kelvin was permanently interested. In his Royal Institution lecture of 1883, reprinted in "Popular Lectures and Addresses," vol. i, he gives an illuminating account of the different lines of evidence that all converge to a cumulative proof that matter is coarse-grained or atomic in structure and set a definite minimum limit to the dimensions of the atom. His deduction of the diameter of the water molecule from the cooling effect observed when a water film is stretched, is one of the most notable of these examples. In his later papers, he accepts Stoney's arguments in support of the atomic nature of electricity and in a paper of curious title "Æpinus Atomized," * he restates the old theory of Æpinus of the nature and relation of positive and negative electricity in a more modern form, by assuming that the negative electricity in an atom is distributed in the form of definite units called "electrions"—or electrons as we should now term them—held in equilibrium embedded in a sphere of uniform positive electrification. This was the first type of model atom put forward. A similar type of atom, developed and worked out in detail by Sir J. J. Thomson, played a notable part in giving a concrete view of atomic structure which was directly amenable to mathematical calculation. In some of his later papers, Kelvin devised types of atoms which, under certain disturbances, broke up with explosive violence, simulating in behaviour the atoms of radium. While keenly interested in such speculations, there remained the curious anomaly that he did not entirely accept the current explanation that radio-activity was a consequence of the successive disintegrations of atoms.

We shall now turn to our main subject. The discovery in 1897 of the individual existence of the negative electron of small mass, and the proof that it was a component of all the atoms of matter, was an event of extraordinary significance to science, not only for the light which it threw on the nature of electricity but also for the promise it gave of methods of direct attack on the problem of the structure of the atom. This discovery of the electron, coupled with the recognition of the atomic nature of electricity, has created a veritable revolution in our ideas of atoms.

The first definite proof of the close relations that exist between electricity and matter we owe to the famous experiments of Faraday on the passage of electricity through electrolytes. It was clear that the simple numerical relations found by him between the electrochemical equivalents of the elements and of their atomic weights could be simply interpreted by assuming that electricity was atomic in character and that the charges carried by the individual ions were integral multiples of a fundamental unit of charge. It is curious to note the long interval that elapsed before the idea of the atomic nature of electricity was generally accepted by scientific men—possibly because of the great difficulty of obtaining confirmatory evidence. The suggestion was mentioned by Maxwell and Helmholtz, although with reservation, but was revived with conviction by Johnstone Stoney, who suggested that the name "electron" should be applied to the fundamental unit of electricity, and made a rough estimate of its magnitude. Actually, as we know, the term "electron" is now used to denote not the actual value of the unit of charge but the free atom of negative electricity. Following the discovery of the independent existence of the electron and the proof of the production of charged ions in gases by X-rays and other radiations, it was implicitly assumed by scientific men that electricity must be atomic in nature, and all the experimental data were interpreted on this view. It was found by Townsend that the charge carried by the ions produced in gases and by the electron itself was numerically equal to that carried by the hydrogen ion in the electrolysis of water, which was taken as the fundamental unit. By the ingenious device of balancing the weight of a charged drop by the attraction of the electric field, Millikan was able to give a very direct and convincing proof of the correctness of this view and to determine the magnitude of the fundamental unit with great precision. Knowing the value of this constant, the electrochemical data give us immediately the mass of the atom of each of the elements. While no one now doubts the atomic nature both of matter and of electricity, it should be noted that the atomic nature of matter is in reality a consequence of the discrete nature of electricity, for we shall

* *Philosophical Magazine*, March 1902.

see that all the evidence indicates that the atom itself is a purely electrical structure.

While most of the carriers of electricity or ions in gases with which we experiment have a unit charge, in a few important cases they have been found to carry multiple charges. A well-known example is the swift α particle from radium which always carries two units, while some of the ions produced in intense electric discharges through vacuum tubes carry multiple charges.

It was soon recognized that the negative electron of small mass was an actual disembodied atom of electricity and that its apparent mass was electrical in origin. J. J. Thomson had early shown (1881) that a charged body in motion behaved as if it had an additional electric mass due to its motion. The moving charge generates a magnetic field in the space surrounding it, resulting in an increase of energy of the moving system. This additional energy is equivalent to the effect produced by an increase of the mass of the body. The experiments of Kaufmann and others on the swift electrons ejected from radium showed that the mass of the electron, while sensibly constant for slow fields, increased rapidly as the velocity of the electron approached that of light. This variation of mass was in good agreement with calculations based on the electrical theory. Later, Einstein from considerations of relativity showed that for any material particle, whether charged or not, the mass m must vary with speed according to the relation $m/m_0 = (1 - \beta^2)^{-\frac{1}{2}}$, where m_0 is the mass for low speeds, and β is the ratio of the velocity of the particle to the velocity of light. Experiment has been shown to agree closely with this calculation. Since there must always be electric mass associated with the movement of electric charges, it is natural to suppose that the mass of the electron is entirely electrical in origin, and no advantage is gained by supposing that any other type of mass exists. If the atom is a purely electrical structure, the mass of the atom itself must be due to the resultant of the electric mass of the charged particles which make up its structure. We shall see that only a small fraction of the mass of an atom can be ascribed to the negative electrons contained in it, but the main part is to be ascribed to the positively charged units of its structure. One of the main difficulties in our attack on the question of atomic constitution has lain in the uncertainty of the nature of positive electricity. Without entering upon the changes in point of view on this important question, it suffices to say that the evidence as a whole supports the idea that the nucleus of the hydrogen atom, i.e. a positively charged atom of hydrogen, is the positive electron. No evidence has been obtained of the existence of a positively charged unit of mass less than that of the hydrogen nucleus, either in vacuum tubes or in the transformation of the radio-active atoms, where the processes occurring are very fundamental in character.

It might *a priori* have been anticipated that the positive electron should be the counterpart of the negative electron and have the same small mass. There is, however, not the slightest evidence of its existence. On the views outlined, the positive and negative electrons both consist of the fundamental unit of charge, but the mass of the positive is about 1 800 times that of the negative. This difference in the mass of the two electrons seems a fundamental fact of nature and, indeed, is essential for the existence of atoms as we know them. The unsymmetrical distribution of positive and negative electricity that is characteristic for all atoms is a consequence of this wide difference in the mass of the ultimate electrons which compose their structure. No explanation can be offered at the moment why such a difference should exist between positive and negative electricity.

Since it may be argued that a positive unit of electricity associated with a much smaller mass than the hydrogen nucleus may yet be discovered, it may be desirable not to prejudge the question by calling the hydrogen nucleus the positive electron. For this reason, and also for brevity, it has been proposed that the name "proton" should be given to the unit of positive electricity associated in the free state with a mass about that of the hydrogen nucleus, viz. about 1·007 in terms of O = 16. A name for this unit will be found very convenient in discussing the inner structure of atoms. In the following, the term "electron" will be applied only to the well-known negative unit of electricity of small mass.

On the classical electrical theory, the mass of the electron can be accounted for by supposing that the negative electricity is distributed on a spherical surface of radius about 1×10^{-13} cm. This is merely an estimate, but probably gives the right order of magnitude of the dimensions, though it should be pointed out that in some recent theories of Compton and others it has been supposed that the electron behaves like a flexible ring whose dimensions are about 10^{-11} cm, or about 100 times the original estimate. Without going into these difficult questions, what little experimental evidence there is seems to me to support the older estimate of size. Taking the view based on the older theory, the greater mass of the proton is to be explained by supposing that the distribution of electricity is much more concentrated for the proton than for the electron. Supposing the shape spherical, the radius of the proton should be only 1/1800 of that of the electron. If this be so, the proton has the smallest dimensions of any particle known to us. It is admittedly very difficult to give any convincing proof in support of this contention, but at the same time there is no evidence against it. From the point of view of simplicity of explanation, it is natural to make the assumption that the proton and the electron are the fundamental units of which all atoms are built.

We shall now pass on to consider the present position of our knowledge of atomic constitution and the evidence in support of the view that the atom is a complex structure made up of protons and electrons. It would take too long to consider in any detail the gradual development in the last twenty years of our ideas on the structure of atoms. Progress has depended mainly on a clearer understanding of the relative part played by positive and negative electricity in atomic structure. It is now generally accepted that the atom is an electrical system and that the atoms of all the elements have a similar type of structure.

The nuclear theory of atomic constitution has been found to be of extraordinary value in offering an explanation of the fundamental facts that have come to light, and is now generally employed in all detailed theories of atomic constitution. At the centre of each atom is a massive positively charged nucleus of dimensions minute compared with the diameter of the atom. This nucleus is surrounded by a distribution of negative electrons which extend to a distance and occupy rather than fill a region of diameter about 2×10^{-8} cm. Apart from the mass of the atom which resides mainly in the nucleus, the number and distribution of the outer electrons, on which the ordinary physical and chemical properties of the atom depend, are controlled by the magnitude of this nuclear charge. The position and motions of the external electrons are only slightly affected by the mass of the nucleus. On this view of the atom, the problem of its constitution naturally falls into two parts, one the distribution and mode of motion of the outer electrons and the other the structure of the nucleus and the magnitude of the resultant positive charge carried by it. In a neutral atom, the number of external electrons is obviously equal to the number of units of positive (resultant) charge on the nucleus.

The general conception of the nuclear atom arose from the need of explanation of the very large deflections experienced by swift α and β particles in passing through the atoms of matter. A study of the number of α particles scattered through different angles showed that there must be a very intense electric field within the atom, and gave us a method of estimating the magnitude of the charge on the nucleus. Similarly the scattering of X-rays by the outer electrons gave us an estimate of the number of these electrons in the atom, and the two methods gave concordant values. The next great advance we owe to the experiments of Moseley on the X-ray spectra of the elements. He showed that his experiments received a simple explanation if the nuclear charge varied by one unit in passing from one atom to the next. In addition, it was deduced that the actual magnitude of the nuclear charge of an atom in fundamental units was equal to the atomic or ordinal number when the elements were arranged in order of increasing atomic weight. On this view, the nuclear charge of hydrogen is 1, of helium 2, lithium 3, and so on up to the heaviest element uranium of charge 92. It has been found that between these limits, with few exceptions, all nuclear charges are represented by known elements.

This relation between the atoms of the elements found by Moseley is of unexpected simplicity and of extraordinary interest. The properties of an atom are defined by a whole number which varies by unity in passing from one atom to the next. This number represents not only the ordinal number of the elements but also the magnitude of the charge of the nucleus and the number of outer electrons. It could hardly have been anticipated that, possibly with few exceptions, all nuclear charges between 1 and 92 would represent elements found on the earth. With the exception of the radio-active elements, the atoms are all stable for intervals represented by millions of years. The atomic weight of an element is not nearly so fundamental a property of the atom as its nuclear charge, for its weight depends upon the inner structure of the nucleus which may be different for atoms of the same nuclear charge.

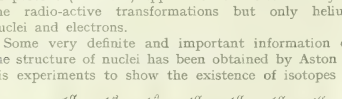
I cannot enter to-night with any detail into the great problem of the distribution and mode of movement of the outer electrons which surround the nucleus. It is now generally supposed that the electrons are arranged in groups or shells round the nucleus. In a very remarkable and comprehensive theory, Bohr has attempted to deduce the distribution and mode of motion of the electrons of all atoms. The position and motion of the electrons are determined by certain relations based on the quantum theory. The whole problem is one of very great difficulty and complexity when we recall that a heavy element like uranium contains 92 electrons which are believed to be in rapid motion round the nucleus. The theory offers a general explanation of the periodic variation in the properties of the elements, and even accounts for the presence of the group of rare earths where the chemical properties of successive elements closely resemble one another. It endeavours to account not only for the light spectra but also for the X-ray spectra of all the elements. While it is too soon to express a definite opinion of how far this theory is capable of explaining the great multitude of facts known about the elements, there can be no doubt that a substantial advance has been made in the attack of this most fundamental of problems which lies at the basis of physics and chemistry.

We shall now direct our attention to the still more difficult question of the structure of the nucleus. The most definite information in this direction has been obtained from a study of the modes of disintegration of the radio-active atoms. In the great majority of cases the atoms break up with the expulsion of a single α particle which represents the doubly charged nucleus of the helium atom; in other cases a swift β ray or electron is liberated. There can be no doubt that these particles are liberated from the nuclei of the radio-active atoms. This is clearly shown by the variation of the atomic numbers of the successive elements in the long series of transformations of uranium and thorium (see Figure on page 616). The expulsion of an α article lowers the nuclear charge of the atom by two units and its mass by four, while the expulsion of an electron raises it by one. On this simple basis, we can at once deduce the atomic number and, consequently, the general chemical properties of the long series of radio-active elements. In this way we can understand at once the appearance in the radio-active series of isotopes, i.e. elements of the same nuclear charge but different atomic masses. The existence of isotopic elements was first brought to light from a study of the radio-active elements. For example, radium B, radium D and the end product uranium-lead are isotopes of lead of nuclear charge 82 but of masses 214, 210, and 206 respectively. As regards ordinary chemical and physical properties, they are indistinguishable from one another, differing only in properties that depend on the nucleus, viz. atomic mass and radio-activity. For example, radium B and radium D both emit β rays but with different velocities, while their

average life is widely different. Uranium-lead on the other hand is non-radio-active. Many similar examples can be taken from the thorium and actinium series of elements. These illustrations show clearly that elements may have almost identical physical and chemical properties and yet differ markedly in the mass and structure of their nuclei.

From the radio-active evidence it seems clear that the nuclear structure contains both helium nuclei and electrons. In the uranium-radium series of transformations eight helium nuclei are emitted and six electrons. It is natural to suppose that the helium nuclei and electrons that are ejected act as units of the nuclear structure. It is clear from these results that the nuclear charge of an element is the excess of the positive charges in the nucleus over the negative. It is a striking fact that no protons (H nuclei) appear to be emitted in any of the radio-active transformations but only helium nuclei and electrons.

Some very definite and important information on the structure of nuclei has been obtained by Aston in his experiments to show the existence of isotopes in



Uranium-radium series

the ordinary stable elements by the well-known positive-ray method. He found that a number of the elements were simple and contained no isotopes. Examples of such "pure" elements are carbon, nitrogen, oxygen and fluorine. It is significant that the atomic weights of these elements are nearly whole numbers in terms of O = 16; on the other hand, elements such as neon, chlorine, krypton and many others consisted of a mixture of two or more isotopes of different atomic masses. Aston found that within the limit of error—about 1 in 1 000—the atomic weights of these isotopes were whole numbers on the oxygen scale. This is a very important result, and suggests that the nuclei of elements are built up by the addition of protons of mass nearly one in the nuclear combination.

From the mass of an atom we can calculate at once the number of protons and electrons in its nucleus. For example, the oxygen nucleus of mass 16 and nuclear charge 8 must contain 16 protons and 8 electrons. From the radio-active and other evidence to be discussed later, it seems probable that the protons are not in the free state in the nucleus, but combine to form very stable helium nuclei each composed of 4 protons and 2 electrons. On this view, oxygen may consist of 4 helium nuclei as secondary units while fluorine of mass 19 and charge 9 may be made up of 4 helium nuclei and, in addition, 3 protons and 2 electrons.

Disintegration of Elements.

You may naturally ask what direct evidence is available to prove that the proton exists as a unit of the structure of the nucleus. We have seen that in the radio-active transformations, only helium nuclei and electrons are ejected but no protons. The obvious method of obtaining some evidence on this point is to effect the disintegration of some of the ordinary elements and to examine the masses and charges of the ejected fragments. There seems to be no doubt that the nucleus structure is held together by very powerful forces and that we can only hope to effect its disintegration by very concentrated sources of energy applied directly to the nucleus. The most concentrated source of energy known to us is the swift α article expelled from radium or thorium. It is liberated with a velocity of about 10 000 miles per second, and has so much energy that it produces an easily visible flash of light on striking a crystal of zinc sulphide. In order to test whether the atoms can be artificially disrupted, I have therefore employed a stream of α particles to bombard the atoms of the material under examination. On account of the minute size of the nucleus, we can expect an α particle only occasionally to get near enough to the nucleus to effect its disruption. We should expect this direct method of attack to be more successful for light than for heavy atoms. If we take a heavy atom of high nuclear charge, the repulsive forces between the positively charged α particle and nucleus are so strong that the α particle is either turned back or loses much of its energy before it reaches the nucleus. In the case of light atoms of low nuclear charge, the α particle probably retains much of its energy on entering the nucleus structure and may be thus more effective in promoting disintegration than in the case of the heavy atom.

Before considering these experiments in detail, it is desirable to say a few words on the effects observed when an α particle collides with the hydrogen nucleus —the lightest and simplest nucleus known to us. When α particles are passed through hydrogen or any material containing hydrogen, occasionally an α particle passes so close to a hydrogen nucleus that it sets it into swift motion. This H particle has sufficient energy to be detected by the scintillation it produces on a zinc sulphide screen. From the principles of mechanics, it is to be expected that the maximum speed communicated to an H nucleus should be 1·6 times the velocity of the colliding α particle. This has been verified experimentally, and it has been found that the maximum range of the recoil H particle, i.e. the distance travelled in air before absorption, is about 4 times that of the colliding α particle. For example, if the H nuclei are set in motion by α particles from radium C of range 7 cm in air, their maximum range is about 28 cm, but, of course, particles of all ranges from 0 to 28 cm due to oblique collisions are also present. These swift H nuclei are liberated not only from hydrogen but from all matter containing hydrogen in chemical combination and in number proportional to the amount of hydrogen.

The first observation indicating the disruption of the nitrogen nucleus was made some years ago. When a stream of α particles is passed through oxygen or carbon dioxide, a few long-range particles are observed which appear to be H nuclei liberated from hydrogen

present in the radio-active source. When dry air or pure nitrogen is used, the number of particles is 3 or 4 times as numerous and of greater average range. These swift particles are bent in a magnetic field as if they were hydrogen nuclei, and it was thus concluded that they arose from the disruption of the nitrogen nuclei due to close collisions with α particles.

Further progress has depended mainly on improving the methods of counting the weak scintillations produced by these particles. Dr. Chadwick and I have made a systematic examination of a number of the lighter elements and have found that similar long-range particles are liberated from boron, fluorine, sodium, aluminium and phosphorus, as well as from nitrogen. The range of the particles in all cases is greater than that of the H particles liberated from free H atoms under similar conditions. For example, using radium C as a source of α rays, the range of the H nuclei is about 28 cm. Under similar conditions the range of the particles from nitrogen is 40 cm, while the range of the particles from aluminium is as much as 90 cm. The range of the particles of the other elements mentioned lies between these two values. Such results show clearly that the presence of these particles cannot be ascribed to some contamination of the material with free or combined hydrogen.

In some recent experiments, we have found that these long-range particles are bent in a magnetic field as if they were hydrogen nuclei. While it is very difficult to measure the mass of these flying particles with accuracy, there can be little doubt that the long-range particles from these elements consist of hydrogen nuclei in all cases. The maximum speed of emission of these nuclei depends on the speed of the bombarding α particle and varies from element to element.

It is thus natural to conclude that "protons" have been ejected from the nuclei of certain light elements by the action of the α particles. It is significant to note that no protons are liberated from elements like carbon (12) and oxygen (16) whose atomic weights are given by $4n$, where n is a whole number. Protons are only observed in elements where the atomic weights are expressed by $4n + a$, where a is 2 or 3. This is simply illustrated in the following list of elements from which protons are liberated. Boron contains two isotopes which are included in the table.

Element	Mass	$4n + a$
Boron	10	$2 \times 4 + 2$
	11	$2 \times 4 + 3$
Nitrogen	14	$3 \times 4 + 2$
Fluorine	19	$4 \times 4 + 3$
Sodium	23	$5 \times 4 + 3$
Aluminium	27	$6 \times 4 + 3$
Phosphorus	31	$7 \times 4 + 3$

These results suggest that the elements are in the main built up of helium nuclei, mass 4, and protons. The α particle is unable to liberate a proton from elements like carbon or oxygen which are built up entirely of helium nuclei as secondary units, but can do so from an element like fluorine which presumably is built up of 4 helium nuclei and 3 protons. As we shall see later, the helium nucleus is so stable a structure that it is probably impossible to effect its disintegration with the swiftest α particle available. Since the speed of the proton expelled from aluminium, for example, is dependent on the speed of the colliding α particle, the results indicate that the proton which is liberated is a satellite of the main nucleus. Under such conditions, it may be possible for the α particle to transfer much of its momentum and energy to the proton and to release it from the system to which it is bound. Such a view is supported by the rather surprising observation that the protons from aluminium—and also from other elements—are ejected in the backward as well as in the forward direction of the α particle. Such an effect is not observed when α particles collide with free H nuclei, and the expulsion of protons in all directions seems to be a characteristic phenomenon of disintegration of nuclei. Such a result receives a simple explanation if it be supposed that in some cases the α particle collides with the proton in such a position that the latter recoils in the forward direction, while in others the proton is driven towards the main nucleus of the atom, describes an orbit round it under the influence of the strong central forces, and emerges again in the backward direction.

Such a point of view is in good accord with the experimental evidence. It should be noted that if the protons circulate as satellites in orbits round the main positively charged nucleus, the forces between positively charged particles must be attractive at these minute distances. The rapid change in the laws of force and, possibly, also in the nature of the forces close to the nucleus, has also been observed in the collision of α particles with H nuclei, and has recently been carefully investigated by Chadwick and Bieler.

It should be borne in mind that the disintegration effected by α particles is on a very minute scale. Only two protons are liberated from aluminium for a million α particles traversing it. This disintegration has been observed only by the utilization of such a sensitive method that the individual proton can be counted. In some cases, the energy of the expelled proton is greater than that of the α particle which liberates it. For aluminium, the proton has a maximum energy about 40 per cent greater than that of the α particle. There thus appears to be a gain of energy in some cases, and this excess energy is presumably derived from the nucleus.

From the radio-active evidence, we know that the nuclei of heavy atoms are built up, in part at least, of helium nuclei and electrons, while from the experiments outlined above it seems clear that the proton can be released from the nuclei of certain light atoms. It is, however, very natural to suppose that the helium nucleus which carries two positive charges is a secondary building unit, composed of a close combination of protons and electrons, viz. 4 protons and 2 electrons.

From the point of view of simplicity, such a conception has much in its favour, although it should be mentioned that it seems at the moment impossible

to prove its correctness. If, however, we take this structure of the helium nucleus as a working hypothesis, certain very important consequences follow. On the oxygen scale, the helium atom has a mass very nearly 4·000, while the hydrogen atom has a mass 1·0077. The mass of the helium atom is thus considerably less than that of four free H nuclei. Disregarding the small mass of the electrons, in the formation of 1 gram of helium from hydrogen there would be a loss of mass of 7·7 milligrams.

It is now generally accepted that if the formation of a complex system is accompanied by the radiation of energy E, the reduction of the mass m of the system is given by $E = mc^2$, where c is the velocity of light. This relation between mass and energy follows not only as a direct consequence of the theory of relativity but can be directly derived from Maxwell's theory, as pointed out by Larmor. On this relation, the energy E liberated in the formation of 1 gramme of helium from hydrogen is equal to $6{\cdot}9 \times 10^{18}$ ergs or $1{\cdot}6 \times 10^{11}$ gramme-calories. This is an enormous amount of energy, large compared even with the total energy emitted during the complete disintegration of 1 gramme of radium and its products, viz. about $3{\cdot}7 \times 10^{9}$ gramme-calories. It can be simply calculated that the energy radiated in forming one atom of helium is equivalent to the energy carried by 3 or 4 swift α particles from radium. On this view we can at once understand why it should be impossible to break up the helium nucleus by a collision with an α particle. In fact, the helium atom should be by far the most stable of all the complex atoms.

It has been pointed out by Perrin and Eddington that in all probability the energy of radiation from our sun and the stars is mainly derived from the enormous emission of energy accompanying the formation of helium from hydrogen. If this be the case, it is easy to show that sufficient energy can be derived from this source for our sun to radiate at its present rate for several thousand million years. The older theories of Kelvin and Helmholtz, where the heat of the sun is ascribed to the gradual concentration of the material under gravity, make the life of the sun much shorter than modern estimates of the age of the earth and appear to be quite inadequate to provide the requisite energy.

This interesting suggestion of the probable origin of the greater part of the enormous energy radiated by the sun and stars is one of the first-fruits of the investigations on the structure of atoms. It is believed that the formation of helium from hydrogen occurs under certain conditions in the great central furnace of the sun and stars. There is no evidence, so far, that this combination can be produced under laboratory conditions. It may be that it can be effected only under conditions of very high temperature and enormous intensity of radiation such as occur in the interior of a sun. Even then the process of formation may go on at a very slow rate and for periods measured by millions of years.

In conclusion, I hope I have made clear in my lecture that most workers on the problem of atomic constitution take as a working hypothesis that the atoms of matter are purely electrical structures and that ultimately it is hoped to explain all the properties of atoms as a result of certain combinations of the two fundamental units of positive and negative electricity, viz. the proton and electron. I have tried to make clear to you to-night some of the more successful methods of attack that have been made on this most difficult of problems. During recent years, unexpectedly rapid advances have been made in our knowledge, but I am sure you all recognize clearly, as I do, that we have only made a beginning in the attack on a very great and intricate problem.

Great difficulties arise the moment we consider why the nucleus of an atom holds together, and progress seems likely to be slow because it seems clear that the ordinary laws of force between electrified particles break down at such minute distances. There are, however, a number of obvious lines of attack that may yield us very valuable information. In particular, a closer study of the modes of transformation of radio-active bodies, where the process of devolution of elements takes place before our eyes, may be expected to give us much more important data. During recent years the study of the γ or very penetrating X-rays from radio-active bodies has progressed very rapidly. The general evidence indicates that the γ rays like the α and β particle have their origin in the nucleus. The study of the γ rays thus gives us information of the frequency of vibration of the electrons which form part of the nuclear structure. In addition, Ellis has shown that it appears probable that the laws of quantum dynamics which govern the motions and vibrations of the outer electrons apply also to the nuclear electrons. If this conclusion can be verified, it offers the hope that we may later be able to form some idea of the detailed structure of nuclei. There are a number of other lines of evidence that will have to be taken into account in formulating any definite theory of the evolution of the elements. Harkins has pointed out some very interesting relations that appear to exist between the relative abundance of elements in the earth and their atomic number, while the close study of stellar evolution should ultimately throw much light on the general problem. Time does not allow me to go further into these most interesting and fascinating problems which still await a solution. If I have been able to communicate to you even a small fraction of the interest I feel personally in these questions my lecture will not have been in vain.

ELECTRIC MOTOR STARTERS.

By J. Anderson, Member.

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Summary.

The paper deals with the practical development of an electric motor starter from the first principles relating to current, torque, and resistance values, to the data required by the salesman.

First it describes the method adopted of working in percentages for all calculations; defines what is meant by starting, accelerating and running torques; refers to the lack of data regarding starting conditions; and gives tables of stored energy in rotors, for the normal load torque during acceleration and for the stored energy of a number of typical machines.

Accelerations are classified as "natural regular," "natural irregular," "forced regular," and "forced irregular," and typical diagrams with automatic contactor and hand-operated starters are shown.

A formula is given for estimating accelerating times and torques, and the number of notches from the point of view of breaking capacity is then considered.

The rating of the resistance elements, and points arising out of continuous and intermittent rating, together with diagrams for air cooling, and radiation and diffusion curves for oil-immersed resistances, are next dealt with.

Certain difficulties for the salesman in tabulating the horse-power and resistance sizes are referred to, and the necessity of higher standard temperature-rises is urged.

Unbalanced rotor currents and the methods of calculating suitable resistance values are dealt with, and the accuracy which can be obtained on test is shown.

Eddy-current, rheostatic stator, auto-transformer and star-delta starters are referred to, and the entirely different type of current and torque curves obtained are shown. Methods of rapidly determining the starter proportions for various duties are given.

Certain points regarding the rating of auto-transformers are raised, and a test showing the effect of unequal tap voltages is given.

In preparing a paper on the subject of electric motor starters the mass of material is so great that there is difficulty in selecting points of sufficient general interest and in limiting the paper to a reasonable length.

To the uninitiated an electric motor starter is the simplest thing possible; it merely consists of a resistance element, a number of contacts, and a handle which is operated more or less carefully. To the initiated it presents an infinity of problems, mechanical, electrical, magnetic, thermal and even chemical. Some of these are fairly easy of solution, and some are so complex that only rough working approximations are possible.

It is necessary to review very briefly the various types of starters and describe their fundamental characteristics, but first it is advisable to deal with certain terms used in this paper.

It has been found that in a general study it is impossible to think of volts, amperes, ohms, horse-power, torques and speeds in actual values, and it is far easier to consider them as percentages. For instance, 100 per cent pressure means the normal line pressure, and 100 per cent resistance means that resistance which passes full-load current at normal line pressure. This resistance is represented by the figure 1 because $R = E/I$

$$\text{Therefore} \qquad \frac{100\ \%\ E}{100\ \%\ I} = 1.$$

If this method is adopted, anything which occurs on one motor with a certain ratio of pressure to current will occur on any other motor with the same ratio, and the actual value of the resistance for any motor may be readily written down.

This statement assumes the characteristic curves of the two machines to be similar, and this is sufficiently accurate for a general study of a given problem.

For example, if it is known from calculations based on an average series-motor characteristic curve with average field and armature resistances, that 60 per cent line resistance and 10 per cent armature diverter resistance gives 10 per cent speed at 80 per cent torque, and the ratings of the two motors are 5 h.p. at 110 volts and 40 amperes, and 75 h.p. at 550 volts and 110 amperes respectively, the required resistances are :—

For the 5-h.p. motor.

$$100 \text{ per cent resistance} = 110/40 = 2{\cdot}75 \text{ ohms},$$

therefore line resistance (60 per cent) = 1·65 ohms, and armature diverter resistance (10 per cent) = 0·275 ohm.

For the 75-h.p. motor.

$$100 \text{ per cent resistance} = 550/110 = 5 \text{ ohms},$$

therefore line resistance (60 per cent) = 3 ohms, and armature diverter resistance (10 per cent) = 0·5 ohm.

The actual speeds reached will differ from 10 per cent by the divergence of the actual characteristics from the assumed average, and by the divergence of the armature resistances from the assumed average, but corrections are readily introduced when absolute accuracy is required. In practice a series of standard curves is drawn for motors with 2·5, 5, 10 and 15 per cent armature resistance.

It is convenient also to assume that percentage torque and percentage current are synonymous. This is practically true for the rotor currents of a.c. slip-ring induction motors, and is sufficiently true for the armature currents of d.c. shunt machines with normal excitation, but it is not true for the line currents of

d.c. series machines or the line currents of a.c. slip-ring and squirrel-cage motors. If the general question is studied on this assumption, however, it is easy to introduce corrections for the various types of machines. These methods were adopted some 7 years ago and have proved invaluable.

The most simple and, theoretically, the perfect form of starter is the liquid type, because it is possible to move the dippers or alter the level of the electrolyte to vary the resistance at a speed which maintains a constant accelerating torque with a minimum line current, but so many difficulties arise in practice that the step-by-step resistance starter holds the field except for the very largest starters for colliery winders where the cost of the various refinements and safeguards is small relative to the total cost.

The chief difficulties are evaporation of the water with creeping of the salt and resulting insulation troubles, arcing or excessive heating with all resistance inserted and the dippers just touching the liquid, and heavy current-rush at the moment of short-circuiting the plates to cut out all the resistance. No doubt these difficulties can be wholly or partially overcome, but the fact remains that this type constitutes a small percentage of the total number of starters in use.

It is necessary at this point to define exactly what is meant by starting torque, accelerating torque, and running torque. It is surprising how loosely engineers use these terms; so loosely, indeed, that it is often difficult to discover which is really meant, and the motor makers themselves are frequently the worst offenders. This is probably due to the fact that the motor maker is chiefly concerned with the performance of his motor on load and at full speed; the starter maker cares nothing for the performance on full load and is concerned only with what happens while the motor is accelerating. He requires a different set of data from that which the motor maker is in the habit of supplying to his customer, and he experiences very very great difficulty in obtaining the data; he requires from the user a different set of data from that which the user is in the habit of giving to the motor maker, and again great difficulty is experienced.

There is abundance of information regarding the power required to drive different machines on varying loads, but one looks in vain for data regarding the starting conditions.

Returning to the definitions: the starting torque is obviously that required to start motion; it is the torque required to overcome static friction and may be far in excess of the accelerating and normal running torques; it may vary from day to day with temperature, and is frequently greater on Monday morning than at any other time, on account of all the belts being stiff and cold, and the oil squeezed out of the bearings.

Once motion has started, the torque falls to that required to produce steady running at a certain speed; this lower torque is the running torque. If it is desired to increase the speed, a torque in excess of the running torque has to be applied, and this is the true accelerating torque; it may have any value, depending on the time in which it is desired to attain full speed. The running torque, from the starter maker's point of view, is generally the torque required to maintain normal full speed at the end of the accelerating period. This torque is practically constant throughout the accelerating period in the great majority of cases; there may be a small difference due to windage and so on at the various speeds, but as a rule it is negligible. It has not necessarily anything to do with the normal full load of the motor or the overloads to which the motor may be subjected; it is generally less than full-load torque because it is customary to take off all the load possible before shutting down.

There are numerous exceptions to the general rule, the most notable being centrifugal pumps and fans where the running torque at low speed is practically only friction, a matter of 5 to 10 per cent, rising as the square of the speed to full-load torque at full speed if the pump is starting against load, or rising to from 30 to 50 per cent if the delivery valve is closed and the pump is merely churning.

The static starting torque is difficult to deal with,

TABLE I.

Stored Energy of Rotor.

Rating (b.h.p.) of motor	Stored Energy in ft.-lb. per b.h.p. at		
	400/700 r.p.m.	900/1 000 r.p.m.	1 300/1 500 r.p.m.
2·5	80	90	90
5	90	100	100
10	100	110	120
15	110	125	140
20	120	140	170
25	130	145	190
30	140	155	220
40	150	175	280
50	170	200	350
60	185	230	425
70	200	260	480
80	210	290	550
90	220	320	625
100	230	350	690
125	265	420	
150	295	—	
175	330	"	"
200	365	"	"
225	400	—	
250	430		
275	455		"
300	480	—	"
350	520	"	"
400	550	"	"
450	580	"	
500	600	—	
550	615		
600	620		
650	630	—	—

because no general rules apply; users sometimes complain that they have to manipulate the starter to the half-way position before the motor starts and the latter then rushes up to speed; naturally this must happen if the initial starting torque is excessive, and the user must do what he can to reduce it.

The accelerating torque is amenable to exact calculation; it depends entirely on the inertia of the moving parts and on the time in which it is desired to run up to speed. If a machine had no inertia there would be no accelerating torque and no accelerating time; it would jump to full speed as soon as the running torque was applied.

It is easiest, from the starter maker's point of view, to think of inertia in terms of the foot-pounds of energy stored in the moving parts at full speed, and to express this relatively to the normal horse-power of the motor because the starter is the last link in the chain; the sizes of the motor and of the machine it has to drive have already been determined and all the starter maker has to do is to supply a starter which will enable that motor to run that machine up with the minimum line current in the time required. He may grumble when conditions are too onerous, or he can draw attention to them when the specified conditions are impossible, but as a rule he can alter nothing. That is why he takes the motor and the load as fixed and, in the daily routine, works on a motor horse-power percentage basis.

Further, it is convenient, in a general study, to

TABLE 2.

Friction Torque and Stored Energy for Various Classes of Machinery.

Ref. No.	Description of work	Friction or load torque at end of accelerating period	Stored energy at full speed
		Per cent	ft.-lb./b.h.p.
1	Toothed gears	—	15/18
2	Loose pulley, as for rotor only	$2\frac{1}{2}$	As in Table 1
3	Shop shafting	20/80 (aver. 45)	800/1 000
4	Hoisting full load on cranes	80/100	6/7
5	Hoisting full load on colliery winders	100	500/1 000
6	Small rolls and bar-bending machines	10	700/1 000
7	Medium punching machines	10/15	2 000
8	Medium shearing machines	10/15	3 000/3 500
9	Large shearing machines	10/15	14 000/18 000
10	Large rolling mills	5/10/15	500/1 000
		5/10	2 000/3 000
		10/20	5 000/8 000
		15/20	18 000/65 000
11	Planing machines	20/40	7 000/10 000
12	Disc saws for wood	20/50	1 900/3 800
13	Band saws for wood	$7\frac{1}{2}$	2 500/10 000 (generally 4 000/10 000)
14	High-speed disc saws for steel	$7\frac{1}{2}$ at start, rising to 20 at full speed	14 000/17 000
15	Travelling motion of a crane with full load	75/100	400
16	Centrifugal hydro-extractor	35/50 at start, rising to 75/100 at full speed	60 000/80 000
17	Centrifugal pump, valve closed	$5/7\frac{1}{2}$ at start, rising to 30/50 at full speed	As in Table 1 for impeller
18	Centrifugal pump, valve open	$5/7\frac{1}{2}$ at start, rising to 100 at full speed	As in Table 1 for impeller, plus, say, 70 for water if no long, horizontal lengths
19	Ram pump delivery against vertical head or accumulator	100	100/200
20	Air compressor starting on by-pass	6	100/200
21	Haulage, clutches out	$7\frac{1}{2}/12\frac{1}{2}$	300/900
22	Haulage, clutches in	100	1 000/2 000
23	Conveyor	100	850/1 000
24	Rubber pulping mill	$2\frac{1}{2}$	50/60
25	Corn grinding mill	100	7 500
26	Lathes and drills	20/25	300

express the stored energy in terms of foot-pounds per motor brake-horse-power, because the various classes of work become readily recognizable, and the confusion caused by the actual values is cleared away.

The first place where energy is stored is in the armature or rotor, and Table 1 gives an idea of the amount to be expected.

These figures are minima, and the actual values for a given motor may be 50 per cent higher; values for horse-powers over 650 are not given because sufficient data are not available. Table 1 has been compiled from data of a large number of motors by most of the leading makers, British, American and Continental;

The case of colliery winders is different, because the hoisting speeds are high and the stored energy in the load, cages, rope, head-gears and drum is so great that the rotor stored energy becomes a small percentage of the total.

The other extreme is reached in hydro-extractors, high-speed saws and rolling-mill work where the rotor stored energy is negligible relative to the total.

A very large number of jobs as actually installed have been tested, analysed and classified, and Table 2 is useful in this connection.

The stored energy of the rotor must be added to the figures in every case.

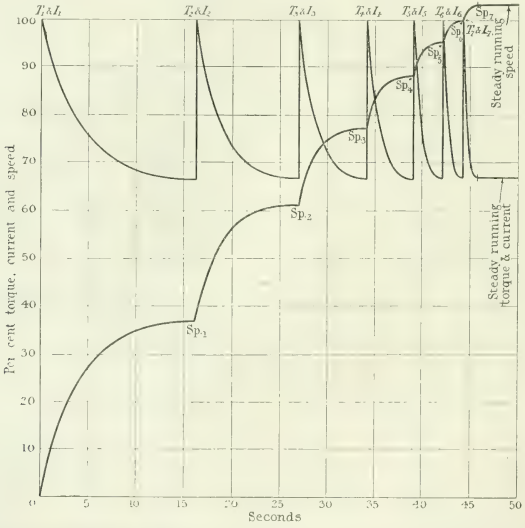


FIG. 1.—Torque/time and speed/time curves for 7-notch starter passing 100 per cent current on first notch with motor having 66·6 per cent load. Stored energy: 1 000 ft.-lb./b.h.p. Motor resistance: 8·8 per cent.

it is not accurate for any particular make of motor, and may be 50 per cent in error in places.

Accuracy is of no great importance because for an accelerating torque of 50 per cent the accelerating times range from about 0·6 second for $2\frac{1}{2}$ h.p. to 5·5 seconds for 650 h.p., and trouble would inevitably arise if starters were designed for such short accelerating times. In practice it is unwise to design the smallest section of the smallest starter for less than 10 seconds. In many cases, for example the hoisting motion of a crane, the stored energy of the rotor is all that need be considered, because the hoisting speeds are so low that the stored energy of the load is negligible.

The figures for large rolling mills of the various types differ widely as shown, and it is necessary in every case to obtain full particulars.

The friction torque for a disc saw rises with the speed, probably due to churning of the cooling water.

The worst duty is provided by the hydro-extractor, being worse than that of the largest rolling mill relatively to the motor size, particularly when the slow-running charging period is taken into account. Many extractors are started on centrifugal clutches to enable squirrel-cage motors to be used, but trouble arises if these clutches operate too soon, particularly when star-delta or auto-transformer starters are used.

The figure of 60 000 to 80 000 ft.-lb. per b.h.p. is given in the table, but it should be mentioned that if the total weight of the basket and load is taken with radius of gyration equal to (measured radius × 0·875), values of 205 000 to 256 000 ft.-lb. per b.h.p. are obtained.

Careful tests seem to show this is too high and that if the weight of the rim, casing and load is taken, the radius of gyration is (measured radius × 0·582), at least for a 48-inch basket.

Expressed in another way it means that the observed stored energy is only 44·4 per cent of that obtained by the usually accepted factor.

A great deal of confusion exists as to what constitutes light and heavy starting. One user ridiculed the idea that a high-speed saw could possibly be heavy duty, because he could turn the saw quite easily with one hand. Such a saw takes 62 seconds to run up to speed with a constant accelerating torque of 100 per cent, so that the torque at the beginning must be 107·5 per cent and at the end 120 per cent.

A convenient formula to use for these starting problems is :—

$$A_t = \frac{S}{T \times 5{\cdot}5 \times K}$$

where A_t = accelerating time in seconds ;
S = stored energy at full speed in foot-pounds per brake horse-power ;
T = percentage of full-load motor torque available for acceleration ;
K = constant depending on the shape of the acceleration curve, conveniently taken as 0·5.

Having reviewed the various classes of work relatively to the normal size of motor used for the purpose, and given a rough-and-ready means of estimating the accelerating time or torque, it is now necessary to see how these facts can be applied to the starter, and the first step is to get a clear idea of the action of a step-by-step starter. For this purpose acceleration may be conveniently classified as follows :—

Natural regular acceleration.
Natural irregular acceleration.
Forced regular acceleration.
Forced irregular acceleration.

When a current is passed through a motor and rotation commences, the speed rises until the back electromotive force cuts down the current to an amount which gives rise to a torque just sufficient to overcome the running friction or load at that speed. When the starter arm is moved to the next notch to cut out resistance there is a current-rush, the peak of which is determined by the ratio of the first resistance to the second, and which gradually dies away as the speed and back electromotive force rise until balance is restored and the current corresponding to the running torque at the new speed is flowing.

If this is repeated on the third and subsequent notches and all the peaks and valleys are equal, the acceleration is called "natural regular"; "regular" because the peaks and valleys are equal, and "natural" because the valley current corresponds to the running torque and cannot be reduced.

Fig. 1 is drawn for a load of 66·6 per cent, the stored energy being 1 000 ft.-lb. per b.h.p., the motor resistance 8·8 per cent, ratio of resistance from notch to notch 1·5, and the current on the first notch and on subsequent peaks being 100 per cent.

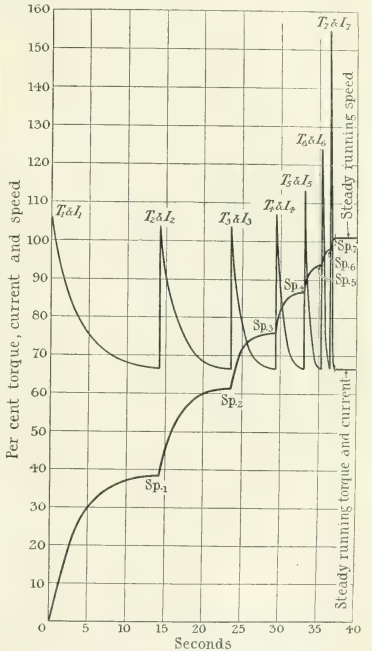


FIG. 2.—Torque/time and speed/time curves for starter intended for use under conditions specified in Fig. 1, with motor having 8·8 per cent resistance. Curves show effect of using with motor having 3·3 per cent resistance.

It is drawn for the correct accelerating time on each notch and it will be noted that these times are in proportion to the ratio of the resistances.

The usually accepted formula for this curve is

$$\text{Ratio} = \sqrt[n-1]{\left(\frac{\text{total resistance}}{\text{motor resistance}}\right)}$$

where n = number of notches.

Fig. 2 shows the effect of overestimating the motor resistance; if the actual resistance is lower than expected, the current-rush on the last notch may be excessive and sufficient to bring out the breaker; the operator may wait on the second last notch for an indefinite period but the breaker will still come out. Incidentally it gives a curve which is typical of "natural irregular acceleration"; "natural" because the valleys fall to the running torque and cannot go

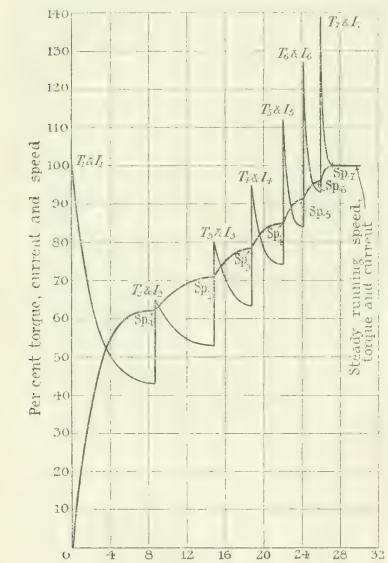


FIG. 3.—Torque/time and speed/time curves for 7-notch starter passing 100 per cent current on first notch, with motor having centrifugal-pump load starting at $7\frac{1}{2}$ per cent and rising to 100 per cent. Stored energy: 1 000 ft.-lb/b.h.p. Motor resistance: 8·8 per cent.

lower, and "irregular" because the peaks are of unequal value.

It is essential to know the motor resistance, that is, the resistance of field and armature for a series motor, and of armature only for a shunt motor. By armature resistance is meant the total resistance including brush gear, commutator and connections, yet even to-day it is not always easy to obtain this information from the motor makers, and a few years ago they seemed to think they were parting with a vital trade secret when they gave it.

The starter maker, in the absence of these data, has deliberately to underestimate the motor resistance, and this frequently means the addition of another notch or two on the starter, with correspondingly increased selling price if the larger dial will go in the same frame, and a very greatly increased price if he has to use the next larger frame.

There is no correct number of notches for a given horse-power because, as a general statement, the greater the number of notches the better the starter, but there is a minimum which should not be exceeded. The current peaks actually found are never so serious as calculated, especially with series motors, for several reasons, the main reason being the inductance of the windings, particularly that of the field winding, and this has proved the salvation of many starters. So much is this the case that a 5-h.p., 440-volt series motor running on a friction load equal to full-load torque may be switched on and reversed without a starter and without injurious currents or sparking at the commutator. It would be quite another matter if the load had high stored energy, necessitating starting times in excess of the time-constant of the circuit.

Fig. 3 shows a better example of natural irregular

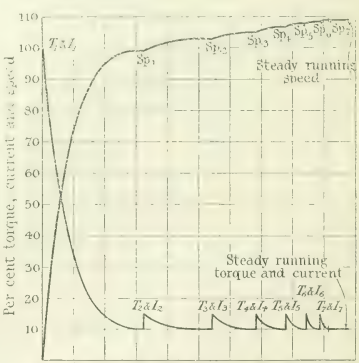


FIG. 4.—Torque/time and speed/time curves. Conditions as in Fig. 1, except that motor load is 10 per cent.

acceleration; it is drawn for a centrifugal pump load starting at $7\frac{1}{2}$ per cent and ending at 100 per cent.

Figs. 4 and 5 show the same starter on light and heavy loads respectively, with natural acceleration and the same stored energy, and it will be seen that the initial current on the first notch remains as before, but that the peaks and valleys are different and the acceleration is natural regular only after the first notch.

Fig. 6 is an example of forced regular acceleration for the same starter as in Fig. 1, but used on the load shown in Fig. 4, transition being made from notch to

notch, not when the valley has fallen to the running torque but prematurely when it has fallen to only 66·6 per cent of this value; the current falls to the running current only on the last notch when all the resistance is cut out and the operator can no longer influence the acceleration. The stored energy is 1 000 ft.-lb. per b.h.p. as before, but owing to the increased torque available for acceleration the total time is reduced to about 7·06 seconds instead of 45·75 seconds in Fig. 1. An ammeter should be installed with a red mark at the valley current when it is desired to operate a starter in this way, and the operator then traverses the contacts at the right time by passing

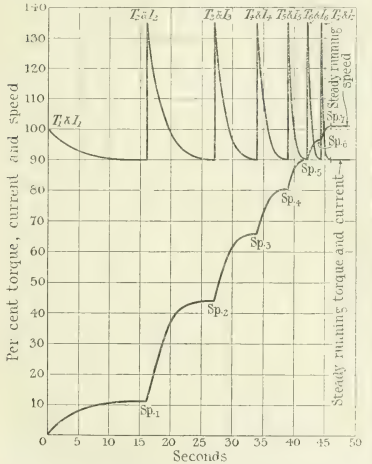


FIG. 5.—Torque/time and speed/time curves. Conditions as in Fig. 1, except that motor load is 90 per cent.

from notch to notch when the current falls to the mark.

Fig. 7 is an example of forced irregular acceleration and is typical of centrifugal hydro-extractors; it is "forced" in the sense that the valleys are never allowed to fall to the running torque, and it is "irregular" in that the peaks and valleys are unequal.

Many highly instructive examples could be given, particularly those for reversing rolls driven by alternating-current motors where reversal is required in the shortest possible time, the motor alternately driving and braking, but that instinctive knowledge of starting conditions which is essential for the starter maker can only be acquired by each designer working out a series of diagrams for himself until it becomes second nature to visualize the curve and say offhand what proportions must be used for the job.

Before leaving this part of the subject Figs. 8, 9 and 10 should be studied. They have been drawn for a 15-h.p. Westinghouse motor on a crane. The size of the motor was calculated on the basis of 10 foot-tons per b.h.p. and the gears were somewhat more efficient, thus making full hook load equal to 90 per cent of motor torque. The resistance passed 62 per cent current (equivalent to 50 per cent torque) on the first notch, and a ratio of 2·07 was taken.

Fig. 8 assumes full hook load and an automatic contactor controller with current relays on all notches,

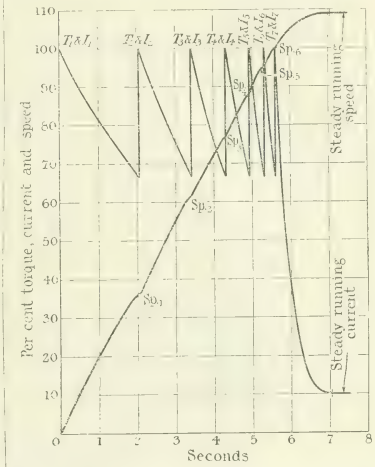


FIG. 6.—Torque/time and speed/time curves. Conditions as in Fig. 4, except that starter is operated to give a peak on each notch equal to that on notch 1, with consequent "forced regular" acceleration.

except notch 1, set for 92 per cent current, equivalent to 90 per cent torque. No motion results and the second notch is immediately cut in, the subsequent automatic operation being as shown, the acceleration being natural regular, and each relay operating in turn when the current falls to 92 per cent. The total accelerating period is about 2·01 seconds.

Fig. 9 is for the same controller hoisting empty hook, the load torque being 5 per cent, assuming the relay on the first notch to be set for 36 per cent current (equivalent to 20 per cent torque). The total accelerating period up to full speed (273 per cent) is about 3·12 seconds, and the acceleration is forced irregular. It will be noted that on the first notch the speed rises to about 77 per cent. When the relay operates, the current rises to only 74 per cent, and as this is less than the setting of the relay on notch 2 the contactor

operates immediately to cut in notch 3, thus sending the current up to 154·5 per cent. A curious effect now takes place, as the field builds up, the back

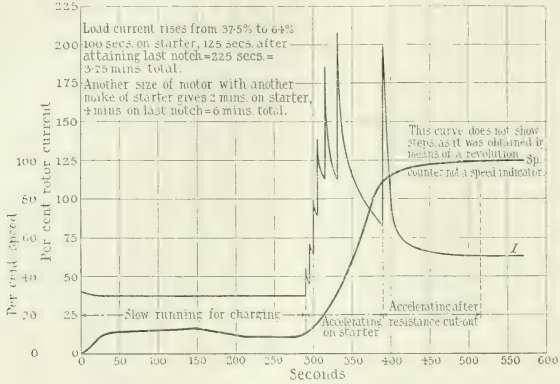

Load current rises from 37·5% to 64%
100 secs. on starter, 125 secs. after attaining last notch=225 secs.=3·75 mins. total.
Another size of motor with another make of starter gives 2 mins. on starter, 4 mins. on last notch=6 mins. total.
This curve does not show steps, as it was obtained in heats of a revolution.
Sp. counter and speed indicator.
I
Slow running for charging
Accelerating after resistance cut-out on starter
Accelerating after resistance cut-out
Per cent speed
Per cent rotor current
Seconds

FIG. 7.—Speed/time and current/time curves for centrifugal hydro-extractor; 48-inch basket.

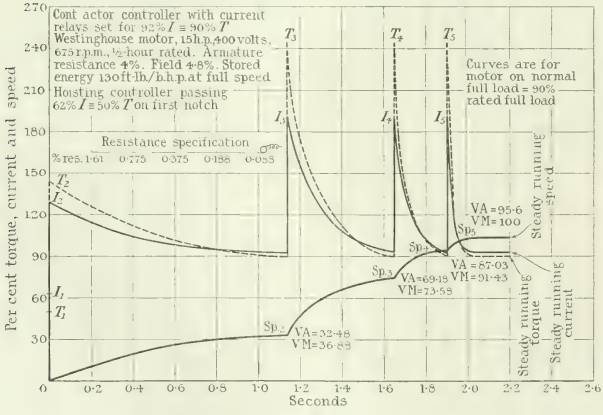

Cont actor controller with current relays set for 92% I = 90% T
Westinghouse motor, 15 h.p. 400 volts, 673 r.p.m., ½-hour rated. Armature resistance 4%. Field 4·8%. Stored energy 130 ft-lb/h.p. at full speed.
Hoisting controller passing 62% I = 50% T on first notch
Resistance specification
% res. 1·61 0·775 0·375 0·188 0·088
Curves are for motor on normal full load = 90% rated full load
VA = 95·6
VM = 100
Steady running speed
VA = 87·03
VM = 91·43
VA = 69·18
VM = 73·58
VA = 32·48
VM = 36·89
Steady running torque
Steady running current
Per cent torque, current and speed
Seconds

FIG. 8.

electromotive force rises and the motor must slow down to 74 per cent speed, or, alternatively, one may say that the motor continues to run at 77 per cent speed and the current drops at once to 92 per cent, causing the next relay to operate, so that in effect the controller changes from notch 1 to notch 4 in one step.

A great deal has been written on the relative merits of current relays and pressure relays, and Fig. 10 has been drawn assuming pressure relays across the armature.

Fig. 8 shows that the relays on notches 2, 3 and 4

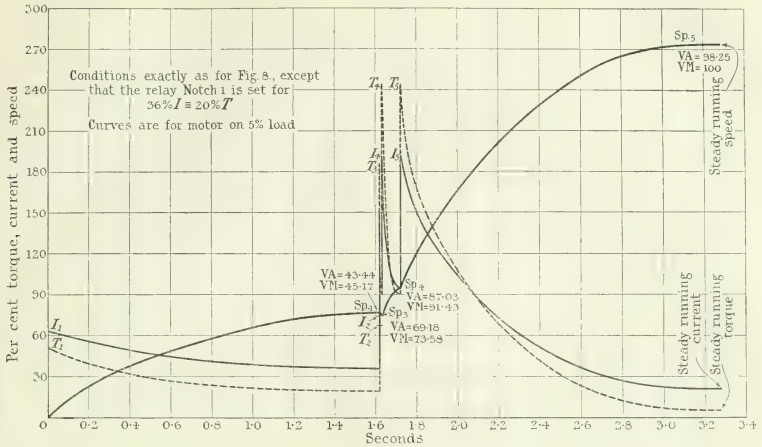

Per cent torque, current and speed
Seconds
Conditions exactly as for Fig 8., except that the relay Notch 1 is set for 36%I ≡ 20%T
Curves are for motor on 5% load
Sp5
VA=98·25
VM=100
Steady running speed
Steady running current
Steady running torque
VA=43·44
VM=45·17
Sp4
VA=87·03
VM=91·43
Sp3
VA=69·18
VM=73·58

FIG. 9.

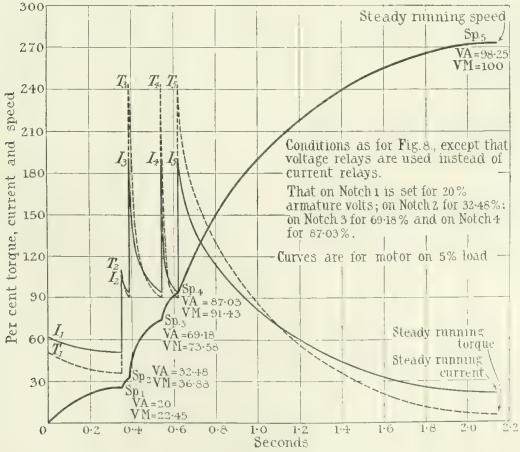

Per cent torque, current and speed
Seconds
Steady running speed
Sp5
VA=98·25
VM=100
Conditions as for Fig 8., except that voltage relays are used instead of current relays.
That on Notch 1 is set for 20% armature volts; on Notch 2 for 32·48%; on Notch 3 for 69·18% and on Notch 4 for 87·03%.
Curves are for motor on 5% load
Sp4
VA=87·03
VM=91·43
Sp3
VA=69·18
VM=73·58
Sp2
VA=32·48
VM=36·88
Sp1
VA=20
VM=22·45
Steady running torque
Steady running current

FIG. 10.

must be set for 32·48, 69·18 and 87·03 per cent pressure respectively to realize that diagram on full load, and it would seem that there is no advantage in a pressure setting versus a current setting; on the contrary the relays must be more difficult to standardize, wind and adjust.

It has been assumed in Fig. 10 that the pressure relay on notch 1 is set for 20 per cent, simply because it must be set for less than notch 2. Again, there seems nothing special to the advantage of a pressure relay, because Fig. 10 would be realized by a current relay on notch 1 set for 51 per cent current instead of 36 per cent as in Fig. 9.

The shorter accelerating period of 2·04 seconds is not due to the use of pressure relays.

Figs. 8, 9 and 10 were drawn for a 5-notch controller instead of the 7 or 8 notches that would be used with a hand-operated controller, because it is customary to give few notches on contactors on account of the high cost and complication with many notches. Comparing Figs. 5 and 8 the peaks are 135 and 192 respectively.

Reverting to Fig. 1, it is necessary to indicate how the accelerating torque over the period is determined. If the running torque is 66 per cent the excess torque in the time available for acceleration is represented by the area of the peaks, and roughly it will be found that the average over the period works out at one-quarter of the excess of the peak over the valley, giving in this case

$$\frac{100 - 66}{4} = 8{\cdot}5 \text{ per cent}$$

If this value is inserted in the formula given on page 623,

$$A_t = \frac{1\,000}{8{\cdot}3 \times 5{\cdot}5 \times 0{\cdot}5} = 43{\cdot}8 \text{ seconds (approx.)}$$

In Fig. 6 the peaks and valleys are the same, giving 8·3 per cent effective torque, but the load torque is only 10 per cent, giving an excess of the valley over the load of 56·6 and making the average effective accelerating torque 64·9 per cent up to the second last saw tooth; the average of the last saw tooth, falling to 10 per cent torque, should be worked out separately. The time on the last notch does not affect the resistance, because it is all cut out, and particular attention need only be paid to it for loads similar to those given by hydro-extractors (see Fig. 7) where the total accelerating time is of importance and the time with all resistance cut out is a considerable percentage of the total.

If current and torque are taken as synonymous the heating current is the constant part plus the R.M.S. value of the saw teeth; if they are not synonymous, separate current curves have to be drawn.

It must be remembered that no claim for accuracy is made for these calculations; they simply show a means of rapidly determining in a commercial manner the general proportions of starters for different classes of work; when so much is open to doubt, from the data supplied by the motor maker to the requirements stipulated by the user or his consulting engineer, extreme accuracy is merely a waste of time. In this connection, it is far better for the user to state in plain language what he desires to do and give the salient data of the machine he wants to start, than to draw up elaborate specifications full of annoying and useless restrictions.

Up to the present the number of notches has been considered only in their relation to the current and torque curves, but sometimes a far more important point arises which necessitates lower ratios and extra notches in the first part of the resistance, and that is the breaking capacity of the starter from notch to notch and from the first notch to the "off" position.

The starter may break the current from notch to notch quite easily, but the wear and tear may be excessive, particularly with brush-type contacts which are very easily roughened and destroyed.

The block or roller type of contact has many advantages, but the relations between the mechanical pressure, mass and radiating surface have to be gone into very carefully by each maker for his own type of contact; the area of the surfaces actually in contact is a secondary consideration with this type.

Such considerations are better dealt with in a paper on switchgear, as they entail a great deal of careful investigation which is particularly irritating because it is difficult to get consistent results, and it is proposed to refer to them only very briefly here.

It has been found that, as a working basis, the breaking capacity required from notch to notch is given by the maximum current at the maximum pressure; thus if on notch 2 the current is 10 amperes and the starter arm is moved back to notch 1 and a difference of potential of 10 volts is established between notches 1 and 2, the breaking capacity of the gap should be sufficient to deal with 10 amperes at 10 volts, not 100 watts, because this has no meaning when talking of breaking capacity; a given switch may break 100 amperes at 100 volts quite easily and fail on 20 amperes at 500 volts. The law connecting amperes and volts for a given quick-break switch and a given breaking distance in air is of the order of

$$\frac{(\text{Amperes})_2}{(\text{Amperes})_1} \propto \left[\frac{(\text{Volts})_1}{(\text{Volts})_2}\right]^{1{\cdot}5}$$

Tests with magnetic blow-out give a different series of results as regards separation of the contacts, but similar as regards arcing distance. Every switch has magnetic blow-out to a greater or less degree, and it is not easy to estimate the allowance to be made. The only way to obtain reliable results is by exact measurements of a large number of photographs of the arcs taken at right angles; comparisons made by eye are entirely misleading.

At the "off" position, two conditions have to be considered; first, making and breaking on the first notch, with the motor "stalled"; and second, breaking to "off" position when the starter arm is allowed to fly back from the full "on" position.

In the first case, the power to be broken is the current on the first notch at line pressure. This is an extremely onerous condition, particularly as the circuit is inductive—indeed, so onerous that no ordinary starter should be subjected to it; a starter should be

used for starting and a breaker for breaking. "Inching" in this way should be done by means of the breaker with the starter permanently on the first notch; the breaker is expressly designed for the purpose and fitted with spark tips readily accessible and cheaply and easily renewable.

If the motor is still "stalled" on the second notch, the power broken in passing back from notch 2 to notch 1 is a very large percentage of full load and it becomes very difficult to break this load in the small distance between the notches. It is true that certain special starters are designed to meet these conditions, but none the less the starter is the wrong place at which to break load.

In the second case, practically no load is broken; if the motor is running on full load generating 90 per cent back electromotive force, the pressure driving the current is only 10 per cent; if all the resistance of the starter, say 100 per cent, is suddenly inserted, the current falls to 10 per cent and the difference of potential at the moment of break is 10 per cent, so that the amount to be broken is 10 per cent amperes at 10 per cent volts.

It is well worth while to experiment with a 5-h.p. motor and note the different arcs obtained on breaking with and without the line resistance when the motor is loaded with a pure friction load which has no inertia, and also with a load having high inertia, and then with the motor "stalled."

The pros and cons of magnetic blow-out or breaking under oil, and the laws connecting amperes, volts, breaking distances and breaking speeds, are too complex to be dealt with in this paper; suffice it to say that the starter maker has to study them exhaustively before he can be confident of his product.

The next stage in the development of a starter is to determine the form which the resistance elements shall take, the way they are to be supported and cooled, and how the taps are to be taken off, etc. Then comes the real difficulty, that is, the rating of the element.

Rating falls into two main divisions, continuous and intermittent. Continuous rating need scarcely be considered in the case of a pure starter, as it affects speed regulation only, but some starting conditions require a slow-running period prior to accelerating to full speed, and if the elements have low specific heat the rating becomes practically continuous. The continuous rating of an element offers a fairly difficult problem.

The main requirement for a continuously rated resistance is the ability to dissipate energy with a reasonable temperature-rise. The ratings vary with every method of construction and with the assembly and materials used, and it must be understood that the following remarks apply to the type of element with which the author is most familiar. It consists of a wire of high-resistance alloy, with negligible temperature coefficient, wound on a stoneware cylinder having a spiral groove that supports the wire throughout its length. This wire is used partly because calculations show that the more costly the wire the cheaper the whole assembly; the use of much cheap wire, such as iron, entails a larger frame, and the cost of the frame is generally greater than the element it contains.

The other reason is that, having gone to all the trouble described in this paper, one does not like to feel it is largely useless on account of the variation of the resistance with temperature, particularly when dealing with creeping-speed controllers for foundry cranes where the resistance values have to be determined with greater accuracy to obtain the specified speeds.

When stainless steel was introduced many people were anxious to use it in starters, but its temperature

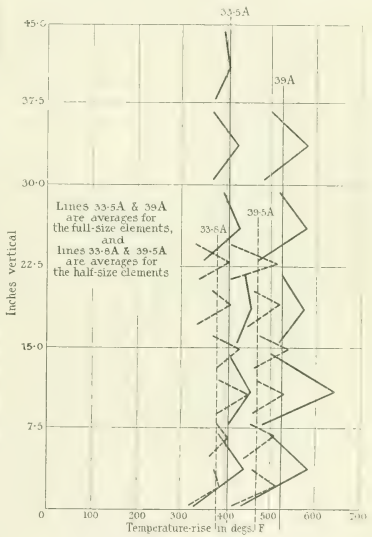


FIG. 11.—Temperature-rises on resistance elements. Units vertical, continuous rating.

coefficient is high and it corrodes easily once a scale has been formed by heating, and breakages develop if the wire is slightly nicked. The temperature coefficient of stainless steel is about 0·001212 per degree F., which means 1·4 times the initial resistance at 350 degrees F. rise. This is a great deal better than mild steel, the temperature coefficient of which is 0·00345, giving 2·2 times the initial resistance with the same temperature-rise, or a resistance wire used by a well-known maker which gives 2·4 times the initial resistance.

In the case of continuous rating, the temperature-rise obtained depends primarily on the watts dissipated

per unit surface of the wire; on the way the wire is shielded by the supports and frame; on the proximity of one turn to another; on the number of turns vertically above each other; on the horizontal distance apart of the elements; and on the side draughts which are difficult to exclude while permitting free access of air. The slightest shielding or side draught causes the temperature to rise or fall very erratically, yet the conditions existing in still air must be taken as the basis, for there is no alternative.

Curiously varying results are obtained with low and high final temperatures, owing to the different radiant and another set of half the wound length were assembled similarly. Currents of 33·5 and 39 amperes were put on the longer set, and 33·8 and 39·5 amperes on the shorter, and the temperatures at numerous points from top to bottom were taken by thermometer with great care when a steady state had been reached. It will be seen that the highest temperature-rise occurs at the middle of each element, whether long or short; that the temperature-rise at the middle of the short element is roughly the same as that one-quarter the way up the longer one; and that the temperatures from element to element do not add up. Much the same sort

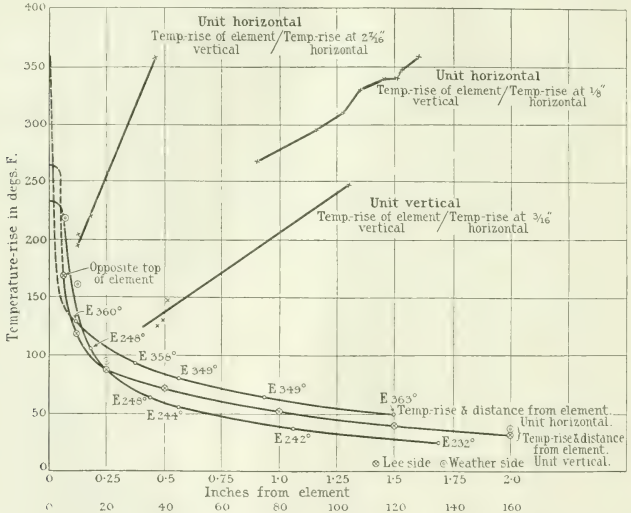


FIG. 12.

components at the two temperatures, and quite different results are obtained if the element is horizontal instead of vertical, even when the total wire surface swept by the air is equal in both positions.

Calculations based on the formulæ accepted for natural draught in chimneys or ventilating shafts in mines would appear to apply, but this is not the case, and a curious effect occurs for which as yet there is no explanation.

It is shown in Fig. 11; a number of resistance elements $7\frac{1}{2}$ inches long over all, and about 6 inches wound length, were assembled vertically on a central iron rod and centred by means of stamped steel spiders, of phenomenon occurs with elements immersed in oil, in which case there can be no side currents caused by an external agency.

The temperature-rise observed at the top of the oil depends also on the head of oil above the elements. The horizontal distance apart affects the temperature-rise, partly by radiation from one unit to another, and partly by each unit working in air heated by convection from its neighbour.

Radiation curves are given in Fig. 12, and it is interesting to note that, with the element vertical, a layer of air about 1/16 inch thick is very nearly at the temperature of the element, while there is no

similar layer with the unit horizontal. The curves indicate that columns of elements should be about 1 inch apart.

The temperature-rise of the frame is asked for in some specifications; it is an extremely doubtful figure, but can be taken very roughly as being one-third the temperature-rise of the elements.

Tests on a resistance element $2\frac{1}{2}$ inches diameter and $7\frac{1}{4}$ inches long totally enclosed in sheet asbestos, black sheet iron unpainted, and bright tinned sheet-iron covers $4\frac{1}{2}$ inches diameter and 10 inches long show that the effect mentioned for air-cooled resistances shielded from side draughts is considerably modified.

With asbestos, the top and middle temperatures of the element are equal and are about 50 per cent in excess of the temperature-rise of the bottom of the element.

With black iron, the top temperature-rise is about 5 per cent in excess of the middle, and with bright iron the middle temperature-rise occurs about midway between the top and bottom temperature-rises.

The extreme range of temperature is about the same percentage whether the element is air-cooled or enclosed.

Table 3 shows other interesting ratios.

TABLE 3.

Heating.

Ratio of Watts to obtain the same Temperature-rise of the Element at the Hottest Part.

Air-cooled	In asbestos cover	In black iron cover	In bright iron cover
1·0	0·56	0·45	0·35

Cooling.

Ratio of Times for Temperature of the Element at the Hottest Part to fall from 400 *degrees F. Rise to* 100 *degrees F. Rise.*

Air-cooled	In asbestos cover	In black iron cover	In bright iron cover
1·0	1·48	1·9	2·4

The table shows that if a correctly rated air-cooled resistance is enclosed in a black iron cover 45 per cent of the watts rating may be put on it, and, if the starting is cyclic, the cooling period must be extended 90 per cent.

The temperature-rise of the cover at the hottest part is equal to that of the element at its hottest part, multiplied by the ratio of resistance wire surface to cover surface.

It might be mentioned, as an instance of the difficulty in getting consistent results, that if small holes $\frac{3}{8}$ inch diameter are drilled in the enclosure opposite the bottom, middle and top of the element, and a thermometer is hung in a small aperture into which the bulb fits loosely on the other side and opposite the middle of the element, the temperature-rise indicated by the thermometer may be varied from 50 to 75 per cent by closing one or other of the little holes.

The effect of shielding by the supports is curious and perplexing and makes it so difficult to predict a

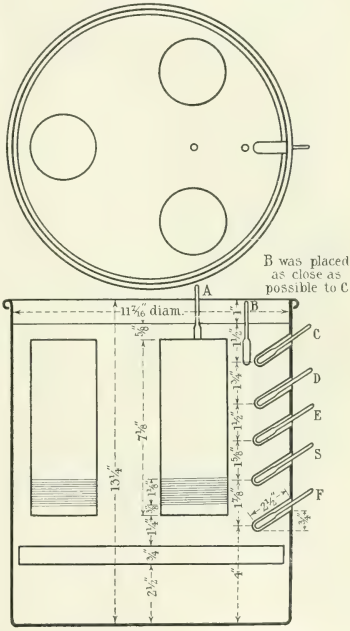


FIG. 13.—No. 1/1 oil starter. 6 100 watts per phase. 30 secs. "on"; $7\frac{1}{4}$ mins. "off." 335 watt-/in.^{2} surface of wire. 1–68 turn pot per phase wound with 12 turns 16 S.W.G. "Heckmum." Tank capacity 1 370 in.^{3} gross, or 103 in. per 1 inch depth. Each pot 40·5 in.^{3} (approx.) or 5·69 in.^{3} per 1 inch depth.

Oil to top of pot = 64·8 in.^{3}
" to pot to C = 75·1 in.^{2}
C to D = 150·2 in.^{2}
D to E = 129·0 in.^{2}
Oil to S = 140 in.^{3}
" S to F = 169·5 in.^{3}
Slate = 27·5 in.^{2} (approx.)

temperature-rise from tests with one section in a given groove, and for other sections in other grooves, that the only practical way is to test out each section separately.

Such are the difficulties with continuous rating. Those with intermittent ratings are vastly greater, because if the heating is complex, the cooling is equally

so, and heating for one short period with cooling for a different period makes the problem one of the most difficult that can be imagined.

An intermittent rating depends on the watts which will raise the temperature of the unit during the heating period the same number of degrees that it cools during the cooling period.

An element with high thermal storage, i.e. specific heat multiplied by weight, is a desideratum for infrequent starting, say once every 4 hours, and the ability to get rid of the heat is not very important.

Consequently, resistances embedded in ceramic material are attractive at first sight, and experimental resistances have been made which will absorb a large number of watts for 10 seconds with a current far beyond the fusing current.

Some of the earliest forms with wire embedded in enamel are still in use, but they have never become very popular.

It seems going rather far to have one type with low thermal capacity and high dissipating capacity for continuous rating, another with high thermal capacity and poor dissipating capacity for infrequent starting, and a third intermediate type for running on a consecutive cycle. The element already described is a satisfactory compromise; it dissipates heat readily because the spirals are scrubbed by the air or oil, yet it has a high thermal capacity because the spirals are in close contact with the stoneware. The intermittent rating of such an element constitutes a very interesting problem, but it would be of no general utility to go deeply into this as all the results would apply only to this particular form.

The following figures show the degree of accuracy which can be obtained in the more simple case of the heating of totally-enclosed direct-current brake magnets.

A single heating and cooling test was made on an experimental magnet; a method of calculating was developed and the final designs were rated from the drawings.

Shunt Magnets.

Size	Time rating from drawings	Time rating on test
	min.	min. sec.
3	15	14 58-3/5
2	30	30 55
1	60	70

Series Magnets.

Size	Time rating from drawings	Time rating on test
	min.	min. sec.
3	15	13 5
2	30	28 45
3	60	60 20

One of the difficulties here is that with shunt magnets the number of watts falls as the temperature rises, while with series windings the watts rise with the temperature.

It may be said that it is possible to utilize the whole of the thermal storage of the pot, but this is inadvisable with the smaller sections of wire because the temperature of the wire varies greatly; where the wire is in close contact it may be at pot temperature, and $\frac{1}{2}$ inch further along where it is not in such intimate contact it may be nearly red-hot.

Under oil there is really no limit except the fusing current, but in practice the limit which has been adopted is that current density which produces marked discoloration due to contact with the oil, and also that temperature-rise which leaves a good margin below the flash point of the oil.

The study of oil-immersed resistances is full of difficulties and perplexities, and yet starters are rated on the basis of watt-seconds and the specific heat multiplied by the total weight of the oil. This might be correct if the whole of the oil were in intimate contact with the resistance element, but this is not possible in practical designs.

Fig. 13 shows a standard three-phase rotor starter with three elements, i.e. one element per phase, and a series of brass pockets soldered into the side of the tank. A drop of mercury was placed in each pocket to give good contact with the thermometer which each contained; and Fig. 14 shows the results obtained with 6 100 watts per phase, 30 seconds "on" and $7\frac{1}{2}$ minutes "off," with 335 watts per square inch surface of wire. Full particulars are given of the test, but many such tests must be made before a working theory can be deduced.

An interesting point to note is the lag of the temperature-rise after switching off. This is perhaps more clearly shown in Fig. 15 which is drawn to compare the results of an element wound with many turns of thin wire, with those on one wound with a few turns of thick wire.

An attempt to study exactly how the heat is transmitted from the wire to the oil near the wire and thence through the body of the oil, formed an interesting investigation. It was thought that a study of the behaviour of water with coloured particles in suspension would be useful, but so many problems were introduced due to air in solution and boiling that this study was not followed up.

One method of tracing the diffusion was by means of little clouds of coloured ink, but the method gave little result because the clouds dissipated imperceptibly.

Pure cooling tests, as apart from diffusion, took a long time; it may seem easy to say that the heat loss is so much per square inch of surface, but questions that arise are: What is the cooling surface; what is the effect of fins, vertical and horizontal; and are there any correct proportions?

Even so simple a thing as the determination of the specific heat of the oil used offered difficulties, and widely varying results were obtained according to the method used. In addition, considerable care has to be taken to obtain a reliable figure.

It would take up too much space to go into the question fully, particularly as the worked-out results

apply only to the shapes and sizes of tanks adopted as standard, and as the whole investigation was conducted by rough-and-ready workshop methods without any pretence at scientific accuracy.

The results were checked by comparison with similar tests with water covered with a film of oil to eliminate error due to evaporation and subsequent condensation on the sides of the tank above water level.

The paper on "Heat Losses in Steam Transmission" by W. C. Cathcart, read before the American Society of Naval Engineers and reprinted in *Cassier's Engineering Monthly*, proved very useful and it should be studied

below the maximum. If, for example, a certain element reaches the maximum temperature-rise with 20 amperes, and the next smaller with 15 amperes, the motor horse-power corresponding to 16 amperes, the 20-ampere element must be used and the temperature-rise will be only 64 per cent of the maximum.

When it is remembered that the temperature-rises accepted as standard are 350 degrees F., and sometimes only 200 degrees F., it is obvious that these maxima are far too low and should be more nearly 600 to 700 degrees F., particularly for elements consisting only of metal and china.

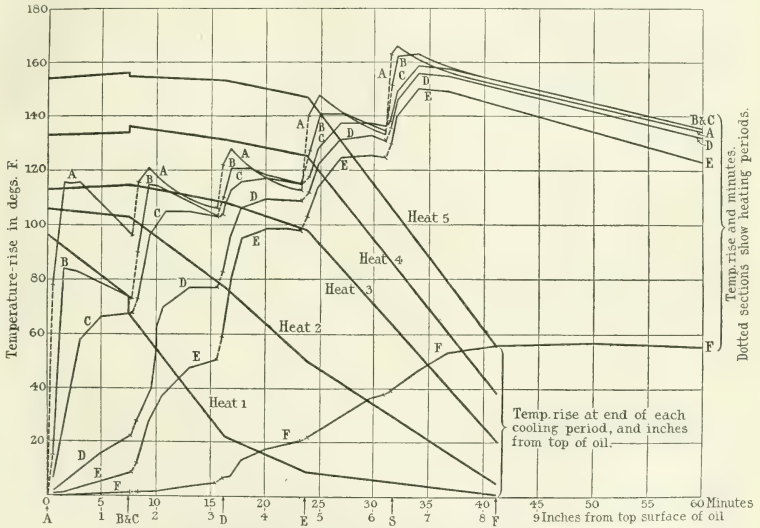

Temperature-rise in degs. F.
180
160
140
120
100
80
60
40
20
Heat 1
Heat 2
Heat 3
Heat 4
Heat 5
Temp. rise at end of each cooling period, and inches from top of oil.
Temp. rise and minutes. Dotted sections show heating periods.
0 5 10 15 20 25 30 35 40 45 50 55 60 Minutes
A 1 B&C 2 3 D 4 E 5 6 S 7 8 F 9 Inches from top surface of oil

FIG. 14.—Heating tests on oil-immersed resistances arranged as shown in Fig. 13.

very carefully by anyone attempting to rate air-cooled or oil-immersed resistances. It would be far better to rate resistances in the same way as motors and brake magnets, that is, by a definite temperature-rise in a definite time, and then to work out curves for cycles so that the capacity on any given cycle could be read off. The next step, after rating the resistances on a more or less rational basis, is to arrange the results in tabular form suitable for the salesman, and there again another difficulty arises. The currents corresponding to the standard direct-current motor horse-powers rarely agree with those which give the maximum permissible temperature-rise of the elements, so that, for the most part, the resistance units are running far

A table of horse-powers and resistance sizes correctly worked out presents the apparent paradox of the smaller horse-power frequently requiring the larger and more costly resistance; a correctly worked out table is practically impossible for alternating-current slip-ring motors, because there are no standard full-load rotor currents. These currents vary enormously for the same horse-power from one motor maker to another, and from Continental to British practice.

One result of such low standard temperatures is that British gear is practically unsaleable on the Continent and in South America, and in pre-war days was very difficult to sell in the Overseas Dominions against German and American competition. The same remark

applies to cable connections and switchgear generally. The waste of cable in connecting starters is sometimes grotesque; people study the I.E.E. Wiring Rules and use those sections specified, irrespective of the time rating and normal working conditions. They seem to forget that these Rules are based on an extremely conservative temperature-rise, considerably lower than that adopted by the French, Germans or Americans, and are for rubber-covered cables, covered up and run for sufficient time on the rated load to produce the final steady temperature; they seem to look only at the figures for rubber and to ignore the tables for other materials. The figures are applied to short lengths of cable on switchgear freely exposed to the air and with considerable end cooling, and to short-rated starter connections without discrimination.

It is customary, on industrial switchgear, to order panels for a current in excess of the maximum it is

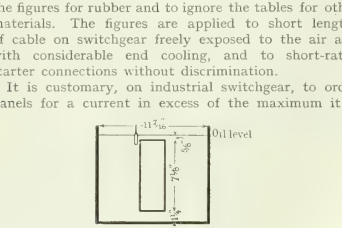


FIG. 15.—Heating tests on oil-immersed resistance elements.

Tests 1 to 4.—68 turn pot filled with 21 S.W.G. Heckmann.
(1) 3·520 watts = 67 watts/in.² surface.
(2) 3·910 ,, = 75 ,, ,,
(3) 9·200 ,, = 175 ,, ,,
(4) 20·769 ,, = 410 ,, ,,
Tests 5 and 6.—31-turn pot filled with 11 S.W.G. Heckmann.
Test 5.—11·500 watts = 133 watts/in.² surface.
,, 6.—29·000 ,, = 295 ,, ,,
NOTE.—Watts/in.² surface not quite in ratio of total watts, owing to slight differences in resistance. 10-second heating period.]

likely to be required to carry, and sometimes the next larger size is put in for mechanical reasons. Cable sections corresponding to the maximum capacity on a low basis rating are insisted upon.

An inspection of any standard gear by a good maker will show what a very large amount of the total space is taken up by the cables, their sealing and clamping of armour and connecting up, and what a relatively small amount is taken up by the part doing useful work.

Standard lines of competitive industrial switchgear have to be based on the average requirements of the average user and should not be expected to comply with exacting specifications.

The remarks on step-by-step starters apply generally to both alternating and direct current, but starters for alternating-current motors present certain problems peculiar to themselves. The resistances are generally connected in the rotors of slip-ring motors, but they may be, and sometimes are, connected in both rotor and stator. They are connected in the stator of squirrel-cage motors.

Resistances in the rotor may be cut out of each phase equally or unequally and may be either star- or delta-connected; the former is the more usual.

Balanced rotor currents and resistances cut out of each phase equally and practically simultaneously must be used when the maximum motor torque is desired, and for speed regulation at or about full load for long periods.

Unbalanced rotor currents with resistances cut out of each phase unequally and at different times may be used for starting at less than the maximum torque (the pull-out torque) or for speed regulation for short periods at or about full load, and for continuous speed regulation at, say, $\frac{3}{4}$ load and less.

The amount of out-of-balance current determines the number of notches, but the standard formula for direct-current and balanced alternating-current starters is applicable to alternating current unequally cut out, with certain reservations.

The current-rush from notch to notch is of relatively small importance; it is important, of course, but the basis of the starter proportions must be the permissible out-of-balance current.

There is no correct number of notches for alternating-current starters, but the greater the number the better the performance of the starter or controller.

It is far more difficult for the user to appreciate the effect of increased notches and diminished out-of-balance rotor currents, because the rotor out-of-balance current is not shown as being out of balance on the stator ammeters, whether the stator is star- or delta-connected.

The following table shows the stator and rotor ammeter readings for various values of rotor resistance.

TABLE 4.

Rotor amperes in phase			Stator amperes in phase		
A	B	C	A	B	C
10	26	32	5·5	6·2	6·2
40	35	18	6·8	7·5	7·4
22	49	64/96 (swinging)	10·5	10/13 (swinging)	10/13 (swinging)
6	39	36	14	15	14·5
38	12	35	14·5	15·8	15
33	34	19	15	16	15
44·5	12	37·5	16	16·9	16·5
44	22	32	16·3	17	16·7
53	37	33	18	18·8	18·8
59	42	25	19	20	20
70	65	10	22	22·6	22·5
77	3	80	23·5	24·5	24·5

Stator: delta-connected.
Rotor: star-connected.
Rotor resistance: star-connected.
Full-load stator current: 30 amperes.

It will be noticed that the rotor out-of-balance current may be so great that the motor is running as practically a single-phase rotor, but the stator currents are nearly balanced. This balancing transformer effect is so great that even the rotor current-rushes on changing from notch to notch are averaged and represented in the stator by quite small swings.

The ammeters are marked as swinging in the third test; this effect is very marked with a small rotor resistance on light load, and constitutes a serious trouble when relays are connected in the rotor; it is more apparent with certain sizes of motors and certain makes than with others, and in some cases the peaks are well over 200 per cent full-load current even with the motor doing little mechanical work.

An exact knowledge of the rotor resistance is perhaps not so essential with alternating-current as with direct-current motors, but it is very useful to have.

There are probably many ways of calculating the notches and sections for unbalanced resistances, and the author has used several from time to time with more or less satisfactory results, but eventually an original method was developed and checked by the test given in Table 5; the tester was simply told to insert the resistances given, put on load to obtain 10 per cent speed and take the readings.

The fact that the observed results agree so well with those expected is largely due to the exceedingly complete data supplied by the motor maker.

The method now in use was developed by the author's assistant, Mr. Fox, and was adopted as being more simple; it is best described in his own words as follows:—

"The method of stepping the resistances for use with a three-phase rotor starter or controller cutting out unequally, i.e. phase by phase and not all phases simultaneously, is based upon the fact that when three resistances of values R, kR, and k^2R, are inserted in the rotor circuits, the motor will behave both mechanically and electrically (as regards the stator) substantially as though equal resistances of value kR were used in each phase. The current in the phase containing resistance k^2R will be $1/k$th of that in the phase having resistance R in circuit.

"Let us consider the case of an 8-notch starter to pass current giving 100 per cent torque on the first notch, for a motor having 10 per cent rotor resistance. If it were of the equally-cut-out type, the resistance per phase would be stepped as follows:—

	Per cent		Per cent
R_1 =	100	R_5 =	26·9
R_2 =	72	R_6 =	19·4
R_3 =	51·9	R_7 =	13·9
R_4 =	37·3	R_8 =	10 (rotor winding)

the formula on page 623 being used, and the ratio working out at 1·39.

"Suppose now that in the rotor phases D, E and F, resistances of values R_1, R_2, and R_3 respectively were inserted. As shown above, results equivalent to using resistances R_2 in each phase would be obtained, with an out-of-balance ratio of 1·39. If resistance R_1 were then changed to value R_4, results equivalent to using resistances R_3 in each phase would occur, still with an out-of-balance ratio of 1·39. Similarly, by successively changing the highest resistance value to that below the lowest in use, a starter giving results equivalent to those of an equally-cut-out type will be obtained. Obviously, to obtain the effects of resistances of value R_1 in each phase, values of 139, 100, and 72 per cent resistance will be necessary.

"The last notches require a little further remark. If, for reasons of manufacturing convenience or the like, it is desirable to cut out one section at a time throughout, the last 3 notches will be cut out thus:—

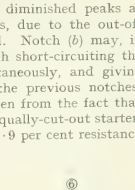
Notch	Phase D	Phase E	Phase F
	Per cent	Per cent	Per cent
(*a*)	19·4	13·9	10*
(*b*)	10*	13·9	10*
(*c*)	10*	10*	10*

* All external resistance short-circuited.

Notches (*b*) and (*c*) give rise to diminished peaks as compared with the other notches, due to the out-of-balance conditions being changed. Notch (*b*) may, in fact, be eliminated, the last notch short-circuiting the two remaining resistances simultaneously, and giving a peak equal to the peaks on the previous notches. That this must be true will be seen from the fact that when considering the equivalent equally-cut-out starter, the penultimate notch requires 13·9 per cent resistance

TABLE 5.

	Notch Number 1	2	3	4	5
Stator Current—	Per cent	Per cent	Per cent	Per cent	Per cent
Expected ..	55	66	73·5	92	113·5
Obtained ..	55	66	73·1	91·5	112·5
Rotor Current					
Expected ..	44·6 30·5 40	66 31·75 59	75·1 51·9 60	94 56 99	132 58 125
Obtained ..	44·6 30·5 40	66 31·75 59	75 52 60	94 55·2 99	132 57·9 125
Speed—					
Expected ..	10	10	10	10	10
Obtained ..	10	9·85	9·85	9·85	9·85
Torque—					
Expected ..	40	51·9	67	87	112
Obtained ..	40	51·9	68·5	95	121



Resistance specification.
Values in ohms.
Rotor volts between rings 1 8 8.
Motor: 25 h.p., 440 V., 3 ph., 25 ~, 750 r.p.m., synchronous speed.

per phase, the last notch, of course, short-circuiting the rotor; the former condition is equivalently obtained on notch (*a*), the latter on notch (*c*). Therefore, to obtain a resistance specification for a rotor starter cutting out resistance unequally (one section at a time throughout) the "equivalent" resistance for the first notch, i.e. the resistance which would be used per phase if cutting out equally, must be determined. Next the ratio must be worked out from a formula similar to that on page 623, viz.

$$\text{Ratio} = \sqrt[n-2]{\left(\frac{\text{equivalent resistance}}{\text{rotor resistance per phase}}\right)}$$

and a specification drawn up as for the phase resistance of an equally-cut-out type as shown in Fig. 16, noting that the equivalent resistance is used on the *second* step [hence the term $(n - 2)$ in the formula]. The first step is given by

$$\text{Equivalent resistance} \times \text{ratio}$$

"If the notch (*b*) above is dropped, as suggested, the formula becomes

$$\text{Ratio} = \sqrt[n-1]{\left(\frac{\text{equivalent resistance}}{\text{rotor resistance per phase}}\right)}$$

The values obtained are then allocated to the phases in cyclic order, as shown in the figure, the last value

winding. In consequence the dimensions become considerable; the iron, surrounded as it is by the coil, is in a bad position for heat dissipation.

Another trouble, more apparent with infrequent starting and non-reversing motors where the choking coil is short-circuited at full speed is that, if the choking coil is small, as it may be for infrequent service, the copper voltage-drop is considerable and the current-rush on short-circuiting is very high if there is an appreciable load on the motor.

It would seem that a better result would be obtained by the use of a true auto-transformer, with more or less laminated cores, which would supply current at low voltages to a massive resistance element capable of being run at a high temperature, say 600° F., without risk of damage to the windings; the auto-transformer could be designed for any convenient loss, and the required torque obtained by adjusting the resistance.

At standstill the choking coil is subjected to full rotor pressure at line frequency; at full-load speed the voltage and frequency are those due to slip, say 3 per cent, and on reversal of the stator at full speed the frequency and voltage are double the normal values; as the eddy-current losses are proportional to the square of the frequency and square of the induction, and the hysteresis losses to the 1·6th or 1·7th power of the induction, a very interesting series of calculations

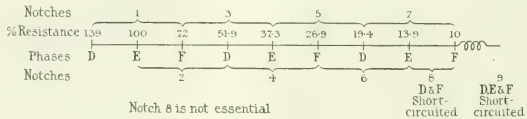


FIG. 16.

representing the resistance per phase of the rotor. To prevent undue heating of one phase of the rotor when the controller is left standing on any notch, a ratio of not more than 1·8 should be employed."

A type of rotor starter which presents quite another series of problems is that frequently known as the eddy-current starter. It consists of a choking coil wound on a solid iron core, and the starting torque is due mainly to the eddy-current and hysteresis losses in the iron at standstill. The accelerating torque during speeding up is due partly to these losses and partly to the I^2R losses in the copper, the former predominating at low speeds, and the latter becoming more important as full speed is reached. It is a very useful form for reversing rolling mills, because only a reversing switch is required; a heavy torque is established on reversal of the stator which first retards the motor to standstill and then accelerates it in the opposite direction.

If this cycle is repeated continuously, however, the iron heats up very much, in spite of the high (specific heat × weight) value of the iron core, and the permissible temperature-rise is comparatively low, say 150 degrees F., on account of the risk of scorching the is opened up, and presents another problem to the starter maker.

An entirely different series of problems has to be considered when the resistance is inserted in the stator or when star-delta or auto-transformer starters are used, because the motor is starting from short-circuit conditions and, if the subject is to be dealt with thoroughly, it is necessary to have the performance curves, i.e. the torque/current, horse-power/current, slip/current, power factor/current, and efficiency/current curves fully worked out from no-load full-speed, to standstill/short-circuit conditions, together with the stator and rotor winding resistances.

At one time it was quite impossible to obtain these data, and a series of suppositious circle diagrams had to be utilized; even to-day the motor makers with one or two exceptions are so unwilling to supply these data that the suspicion arises that in many cases they do not possess them.

The characteristics of starting conditions where stator rheostatic, auto-transformer or star-delta starters are used, are light starting (initial) torques and almost any starting time.

The saw-tooth curves are no longer characteristic

and that shown in Fig. 17 is typical. It is drawn for 10 000 ft.-lb. per b.h.p. stored energy, and the small kick on cutting out the line resistance is not shown. The current curve is square-shouldered instead of saw-toothed, and the torque curve bears no resemblance to the current curve.

An interesting series of curves are those for centrifugal pump loads for which this class of starter is quite suitable, but they are not shown here.

Fig. 18 has been worked out for various amounts of line resistance and, if the load torque is known, a glance at the curve shows how much current must be passed on the first notch; it shows how the motor torque and current vary while running up to speed; and if the load torque is laid off on the diagram as has been done for centrifugal fan or pump loads, it can be seen at a glance how many notches the starter should have.

Take, for example, the fan or pump load starting at 10 per cent torque and rising to 100 per cent as the speed rises.

A current of 150 per cent on the first notch will not start it, but 250 per cent current will, and the speed will run up to about 70 per cent (30 per cent slip) while the current will have fallen to 210 per cent; if the next notch has a resistance which should pass 350 per cent current at standstill, the motor will run up to 95·5 per cent speed (4·5 per cent slip), and the current will rise at change-over to 285 per cent and fall to 120 per cent; if all the resistance is now cut out the motor will run up to 97 per cent speed (3 per cent slip), and the current will rise to 150 per cent and fall to 100 per cent.

Results of calculations worked out from Figs. 17 and 18 are conveniently recorded as shown in Fig. 19, the arrangement of which is due to Mr. Fox.

If the load torque during acceleration is constant at 40 per cent, a glance shows that a current not less than 350 per cent must be passed on the first notch,

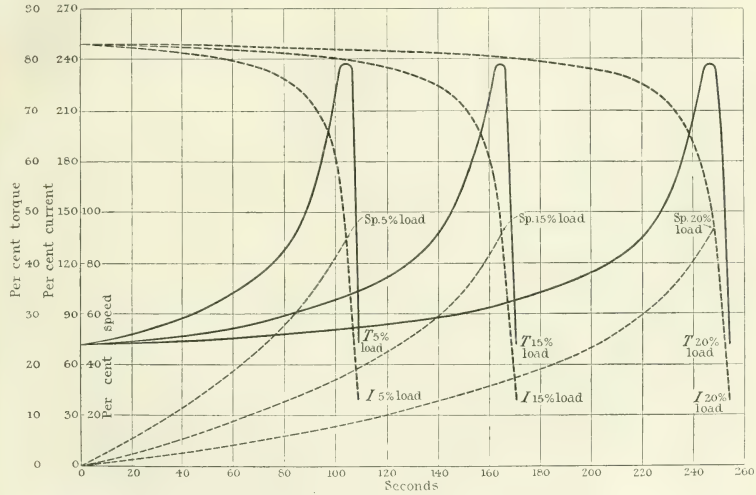


FIG. 17.—Rheostatic stator starter. Line resistance passing about 250 per cent current. Drawn for a stored energy of 10 000 ft.-lb./b.h.p. At 20 per cent friction load the average and R.M.S. currents are about 95 per cent of initial current. Small kick on finally cutting out line resistance not shown.

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If 400 per cent current is passed, the margin of motor torque will be ample because this point falls on the cross; the time will be 38 seconds and if the motor is thrown direct on to line there will be a very large margin of excess torque and the accelerating time will be about $8\frac{1}{2}$ seconds.

If the load is a centrifugal fan load running up to 100 per cent torque, reference to the other curves shows

that it will not start with 250 per cent current; and that with 300 per cent current on the first notch and a suitable starter it can be made to run up in 79 seconds with 5 000 ft.-lb. per b.h.p. stored energy. 1 000 ft.-lb. would be a high figure, and 16 seconds more than a normal time.

There is an apparent discrepancy between these figures and those used when discussing Fig. 18; the explanation is that the latter figure is drawn for a starter properly proportioned to give current-rushes equal to the initial current on changing from notch to notch.

Intermediate curves should be drawn and the set repeated for motors having, say, 400, 500 and 600 per cent short-circuited current, and then the whole series should be re-calculated for auto-transformers with various tap voltages.

The auto-transformer curves also serve for star-delta and series-parallel starters because these act like an auto-transformer with one tap and without the voltage-drop in the transformer windings.

The starter maker has, then, a means of tackling intelligently and quickly any starting problem.

It is common practice to use these starters on any machine requiring low starting torque without special attention to the accelerating time; if the average current over the period is 80 to 95 per cent of the initial, and the initial is 250 to 350 per cent, it must be bad for the motors and cause excessive heating and trouble due to repeated expansion and contraction. Yet specifications come along for auto-transformer starters with a 2-minute accelerating time once every 10 minutes, and on occasion even more frequently; for such specifications the transformer becomes larger than it would be if it were continuously rated.

Table 6 shows the torques obtained from auto-transformer taps; a transformer was connected up using equal and unequal taps on the three phases, with the results shown.

If the friction torque is taken as 24 per cent, the observed accelerating times in column 4 correspond to the torques in column 5. The latter correspond fairly to the torques in column 6, which is based on the assumption that the unequal taps gave a mean torque and do not correspond to the torques in column 7, which is based on the assumption that the effective torque is that of the lowest tap and that the higher taps on the other phases have no effect.

The rating of rheostatic stator starters follows the general lines already described, but new problems arise in rating the auto-transformers.

An inspection of Fig. 19 in conjunction with the starting conditions given in Table 2 shows that a 30-second rating is ample for average conditions; in fact,

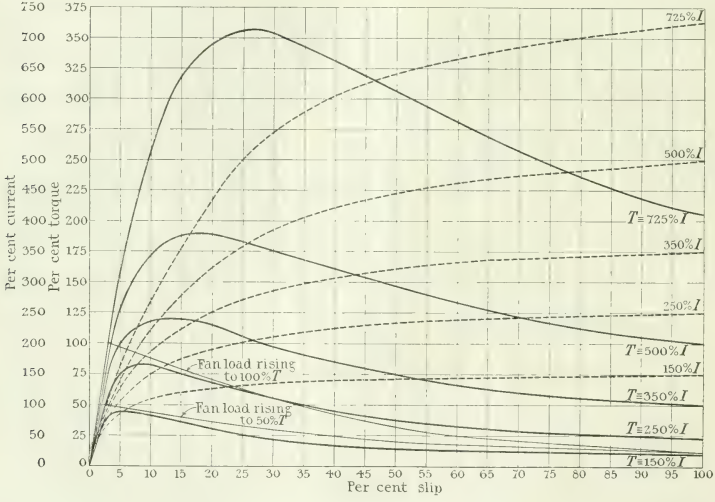

FIG. 18.—Rheostatic stator starter. Torque and current curves with various amounts of resistance in line. Light lines represent driving torques for fan loads.

the vast majority of auto-transformer jobs do not require more than 10 seconds per start.

Tests show that the only factor that matters is the temperature-rise of the copper, i.e. the I^2R losses, and that the iron has no time to heat. For short periods, e.g. 10 to 30 seconds, the rating is based on the specific heat multiplied by the weight of copper; the true cooling is very poor and an auto-transformer is particularly unsuitable for continuous-cycle starting.

TABLE 6.*

Unequal Taps on Auto-transformer Starter.

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
Taps in phase			Secs. to run to 83 % speed	Torques in ratio of times taking 24 % friction	Torques as mean square of taps	Torques corresponding to lowest tap
A	B	C				
0·5	0·5	0·5	Does not start	25	25	25
0·75	0·5	0·5	6	33	33·6	25
0·75	0·6	0·5	5	34·8	37·6	36
0·6	0·6	0·6	4·5	36	36	36
0·75	0·6	0·6	4·0 +	37·5	41	36
0·75	0·75	0·5	3·0 −	42	42·3	25
0·75	0·75	0·75	2·0 +	51	51	56·25

There is little advantage in oil immersion, because the oil cannot circulate freely round the windings. Even if it could there would be little effect at a temperature-rise of 100 to 150 degrees F.; the maximum increase in rating that can be traced to the oil is about 10 per cent and the author neglects it in his calculations.

The chief advantage of the oil is that it excludes moisture, prevents the cotton covering charring, and permits the use of a fairly high temperature-rise, say 150 degrees F., with perfect safety.

A point which requires consideration is the magnetizing current; if the iron is cut down drastically this goes up and may become very important; the designer of an auto-transformer for starting purposes has to discard many of his preconceived notions acquired when dealing with transformers for continuous duty. One of these is the question of regulation, which is determined by the temperature-rise in the period. Apart from this it is of little consequence, because the function of an auto-transformer is to reduce the line current and the pressure at the motor terminals, and it matters little whether this is due purely to transformation or not.

If there is a rather large drop in the windings it is merely a question of using the next higher tap.

It is necessary to decide whether to rate for a definite torque and time so that the higher taps necessarily mean shorter times, or to rate for constant time on all taps so that the higher taps mean greater torque and a correspondingly greater duty. Buyers are not at all clear as to what they want, and are apt to argue one way or the other according to circumstances.

This paper has given only an outline of the problems confronting the starter maker; many important and interesting matters are not even mentioned and others are passed over with little notice, but if the paper leads to a more general recognition that a starter is something more than a bit of wire, a few contacts and a handle, it will have served its purpose.

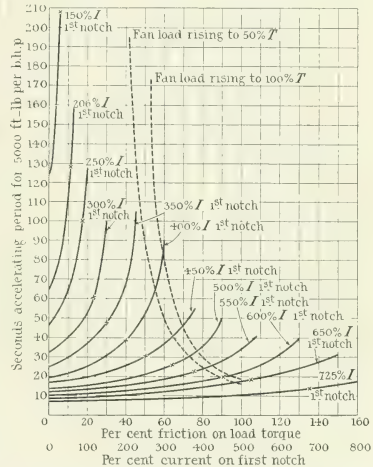
150% I 1st notch
Fan load rising to 50% I
Fan load rising to 100% I
200% I 1st notch
250% I 1st notch
300% I 1st notch
350% I 1st notch
400% I 1st notch
450% I 1st notch
500% I 1st notch
550% I 1st notch
600% I 1st notch
650% I 1st notch
725% I
1st notch
Seconds accelerating period for 5000 ft.-lb per b.h.p.
Per cent friction on load torque
Per cent current on first notch

FIG. 19.—Rheostatic stator starter curves, drawn for motor having 725 per cent short-circuit current. Calculated for 5 000 ft.-lb./b.h.p. stored energy.

Use of full line curves.—Crosses show points which should not be exceeded to allow of sufficient excess motor torque to overcome static friction. For example, constant load or friction torque during acceleration of 40 per cent. Cross on 400 per cent current curve corresponds, so sure to start; accelerating time 38 seconds for 5 000 ft.-lb./b.h.p. and pro rata for other amounts of stored energy. Could use 350 per cent current first notch, but balance of excess torque to overcome static friction very low; accelerating time 68 seconds.

Use of dotted-line curves.—These are for fan loads. To take example, if passing 300 per cent current first notch, with load rising to 100 per cent, accelerating time is 78·5 seconds with 5 000 ft.-lb./b.h.p. With load rising to 50 per cent, accelerating time is 50 seconds.

APPENDIX.

UNEQUALLY-CUT-OUT ROTOR RESISTANCES. PROOF OF METHOD.

Field has shown that the voltage-drop in three star-connected unequal resistances connected to a three-

* Stator steady running current 43·4 per cent full load at full speed, equivalent to 28 per cent torque from characteristic curves. It is known from previous tests that the torque rises with the speed on this particular load, so that 24 per cent torque at 83 per cent speed is approximately correct.

phase supply may be determined graphically by drawing an equilateral triangle whose sides represent to scale the voltage between lines, and imagining the values of the conductance of each phase as a weight at each corner of the triangle; the centre of gravity of the triangle is then the position of the neutral point, and lines drawn to each corner of the triangle from this point will represent in phase and magnitude the voltage-drop in the resistances concerned.

Fig. 20 shows such a construction for resistances in A, B, and C having the relative values R, Rk, and Rk^2.

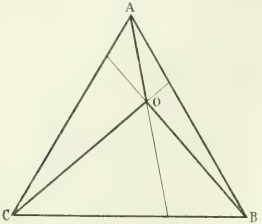

FIG. 20.

Elementary geometry and trigonometry show that the following relations occur:—

$$AO = \frac{AC}{\sqrt{(k^2 + k + 1)}}$$

$$BO = \frac{AC\sqrt{(k^2 - k + 1)}}{\sqrt{(k^2 + k + 1)}}$$

$$CO = \frac{kAC}{\sqrt{(k^2 + k + 1)}}$$

These give the voltage-drops across each resistance as fractions of the line pressure.

The currents will be:—

In A, $$\frac{AC}{R\sqrt{(k^2 + k + 1)}}$$

In B, $$\frac{AC\sqrt{(k^2 - k + 1)}}{kR\sqrt{(k^2 + k + 1)}}$$

In C, $$\frac{AC}{kR\sqrt{(k^2 + k + 1)}}$$

The power per phase dissipated by the resistance will be:—

In A, $$\frac{AC^2}{(k^2 + k + 1)R}$$

In B, $$\frac{AC^2(k^2 - k + 1)}{(k^2 + k + 1)kR}$$

In C, $$\frac{AC^2}{(k^2 + k + 1)R}$$

Total, $$\frac{AC^2}{kR}$$

Dealing with relative values as hitherto, the last equation may be rewritten thus:—

$$kR = \frac{(\text{line volts})^2}{\text{torque} \times \text{slip}}$$

This has been called the "equivalent" resistance of the controller, since three equal resistances of this value give a similar effect to three unequal resistances of values R, kR, and k^2R. The magnitude of kR is usually required, as has been shown, for use in connection with the first notch of a starter or controller, and in this case the slip, being unity, cancels out.

As shown in the paper, any movement round the controller towards the full-on position changes the value of the highest resistances to a value equal to $(1/\text{ratio}) \times$ the lowest, as each notch is reached, and, as the relationship R, Rk, Rk^2 is preserved, the figure still serves, the phase letters A, B, and C moving round it cyclically as each change is made.

The foregoing method assumes that the rotor phase volts and currents are in phase, and, although this is not strictly true, the error involved by the assumption is quite negligible in practical work.

SOUTH MIDLAND CENTRE, AT BIRMINGHAM, 15 MARCH, 1922.

Mr. W. Wilson: There is a tendency among engineers to leave out of consideration the statical portion of their equipment, and to direct an undue amount of attention to the motor. It should, however, be realized that the great majority of the advances which are being made in electric drives to-day are due to improvements in the design of the controlling apparatus. The motor has apparently reached almost its final form, and it is chiefly on account of the important developments that are taking place in connection with the design of starting and controlling gear that the application of the electric motor is still extending rapidly. In addition to giving valuable formulæ and tables the author has directed attention to the difficulties under which the starter designer labours through the uncertainty of the data on which he has to base his calculations. The resistance of the motor to be dealt with has been specially mentioned; but, in addition, even greater uncertainty is introduced by variability in the speed of operating the starter, and extensive uncertainty also as to the nature of the load. The result of this usually is that very wide allowances are made in designing standard starters, which are therefore considerably larger, contain a greater number of steps, and are much more costly than should be necessary. Dealing first with the speed of operation, I am glad that the author has shown so clearly that, in order to obtain the calculated results, the starter handle has to be moved at a rate which increases in geometrical progression from step to step. Only last year an important paper on the design of this class of apparatus showed the steps in the acceleration as a series of symmetrical saw-teeth, in which the

intervals were all equally spaced. Under the latter conditions, the heights of the current peaks would not by any means have been equal but would have decreased rapidly as the acceleration proceeded, until those at the end of the operation were practically non-existent. The important point to note, however, is that unless the acceleration is either automatic, or is hand-performed in such a way that the speed is exactly right at every step, the results secured in practice will be very different from those given, for example, in any of the curves in the paper; and I think that a considerable improvement in this respect could be effected if starters were accompanied by an instruction that the correct method of operating the handle is to move it slowly at the commencement, and to increase the speed progressively as the final step is reached. It is probable that the number of steps could be halved if it were not for this uncertainty as to the rate of acceleration. In contactor installations, as the author has pointed out, fewer steps are employed, although he has not been quite fair to this piece of apparatus in implying that this is due to its comparatively high cost. As a matter of fact, it is permissible to employ fewer steps because the rate of acceleration can be closely governed, and therefore the allowance to provide for uncertainty in this respect is very much reduced. With regard to uncertainty as to the load, there are two distinct methods whereby a line of starters can be designed. The more exact would consist of treating each individual case separately as the order is received; while the more usual method is to design a series of standard models, each to be used with a given motor and class of load. Either of these alternatives involves a great amount of organization if a close design is to be achieved. The first renders supply from the factory almost compulsory. Every case then becomes a special order, and a very carefully systematized and indexed scheme for stocking the component parts will require to be thought out in order to minimize the special work required. In employing the second method there is an equal need of organization in the classification of the loads and the motors. The present system tends to pay chief regard to the motor, or rather to the horse-power rating, the actual load being totally disregarded. Unfortunately for this system the motor is only the intermediary and, as the author has pointed out, the important factor is not even the actual running load, but the load during the period of starting. It should not be sufficient to specify that a starter is required for a motor of a given horse-power, when the actual starting load may be derived from a mere loose pulley, or, to go to the other extreme, from the acceleration of a cream separator involving a very large amount of inertia. I am strongly of opinion that it would tend to a better result if far more attention were devoted to the starting load, even if the motor itself had to be partly ignored. Even with the present system a motor of a given rating may be of several sizes, according to the speed at which it is designed to run. This entails several different armature resistances, and thus a wide approximation is involved on this account alone. A striking example of the difference in bulk between a closely designed starter and the usual standard approximation can be seen in any machine shop in which the large machines are driven by electric motors. Almost invariably these motors are operated by standard starters mounted upon the walls or upon a pillar in the shop, and these, not being specially adapted for their task, are bulky in the extreme. If these be compared with a similar machine, upon which the motor and the starter have been mounted by the makers, who have taken advantage of the conditions to design the apparatus closely, the starter may be less than a quarter of the size that is usual in the other case. Now machine tools are in nearly every case started at no load; and in carrying out a number of tests leading to the design of such starters, I have found that a 5-h.p. shunt motor can be safely started with only 2 steps of resistance, the whole operation taking, say, 2 seconds. The usual standard starters require 7 or 8 steps, and the resistances are designed to be in circuit for anything up to 1 minute. The difference in the space taken up by the resistance units in the two cases can be easily imagined. With regard to the voltage and current-limiting systems for accelerating contactors, I am in agreement with the author as to the superiority of the latter. The weak point of the voltage method is that the resistance of the coil alters materially as it heats up, with the result that the accelerating points are radically changed if the machine has been in service for some little time. Some makers have endeavoured to compensate for this and have produced complicated designs for the purpose; but the fact that almost every contactor installation, with the sole exception of a few small ones of about 2-h.p. capacity, are controlled by the current-limit method would indicate that the voltage method has not justified itself. Fig. 9 appears rather strange to me in that, as a result of starting a current-limit system at no load, 4 contactors have apparently closed in less than $\frac{1}{4}$ second. Now the interval between the closing of two contactors is made up of two portions; the first is the time taken by the peak current to drop to normal, and the second is the natural time-lag of the relay armature, i.e. the time taken for the armature itself to drop to its final position after it has been released by the falling of the current peak. In practice the latter portion alone is comparable to $\frac{1}{4}$ second for each relay. This limits the rate of acceleration at no load to a certain value which should be made equal to the maximum safe one for the given conditions. It would be interesting if the author would give details of the species of relay from which the peculiarly energetic results shown in Fig. 9 were obtained. The author mentions that the peaks are found to be somewhat short of the calculated value in practice. An American designer has stated that these actually amount to very nearly two-thirds of the calculated value in the great majority of cases; and where I have been able to check these by actual measurements this estimate has been very nearly borne out. I should like to ask the author if his experience would serve to corroborate this.

Mr. W. J. Line: When starting switches are on the limits of their breaking and sparking capacity on the first two or three contacts it may be an advantage intentionally to design resistance steps for the results

shown in Fig. 2, in which the later peaks are higher than the earlier ones. This relieves the duty on the earlier contacts and puts more on the later ones which have a reserve. Excessive peaks should not, of course, be allowed. This method I have advocated for a number of years; it is fully explained on pages 182–183 of a book * to which I contributed the chapter on design and several others. With regard to temperature tests on resistances for rating purposes, I suggest that for starting duties reliance cannot be placed on thermometer tests, owing to the poor thermal contact between the resistance wire and the thermometer bulb, and also to the lag and reduction in readings due to the mass of the mercury relative to the adjoining resistance wire. More accurate results are obtained from the thermal capacity of the resistance material calculated from its mass and specific heat, with, if necessary, a small percentage allowance for the heat dissipated during the start. These calculations should be made for the maximum permissible temperature-rise advisable for the particular resistance material, or for the temperature-rise which it is desired to obtain, if lower. For determining the dissipating capacity on continuous or intermittent load by measuring the ultimate steady temperature with a given load, with the object of rating a starter for a succession of starts, thermometer methods may be fairly accurate, but increase-of-resistance methods (as also suggested by Mr. Angold) often give equal or better results. For accurate work I have used mostly these methods and not thermometers. For the determination of the dissipating capacities of given units, sample units may have to be wound with wire having a marked and known temperature coefficient, instead of the normal resistance wire. Table 4 shows some remarkable figures for out-of-balance currents in three-phase rotors, especially in the last line where, as the author has pointed out, the rotor is running practically single-phase. My experience in starting motors with the rotor unbalanced indicates, however, that under such conditions a machine could only run nearly light, and would neither start nor accelerate on anywhere near full-load torque, but would fall out of step. I do not agree that the currents in the stator are really practically balanced. They may appear to be, because the frequency of the pulsations in the stator current is too high for the ammeter to follow, but actually the current in each supply line and phase of the rotor winding is pulsating, the current peaks and valleys continually circulating from phase to phase. That this is so can be seen if by insertion of a suitable amount of unbalanced rotor resistance the motor is run extremely slowly, under which circumstances the pointer of the ammeter in any one line travels up and down the scale between limits which can be read. Also, if a motor is started up slowly with unbalanced rotor, and the stator ammeter is carefully watched, the pointer fluctuates up and down at an increasing speed as the motor accelerates, and finally, with a quiver, settles at a steady reading when the frequency of fluctuation is too high for the instrument to follow. These fluctuations are, of course, not those due to cutting out resistance steps, it being understood that the phenomenon described will occur while the resistance in the rotor phases remains constant. I suggest that the swinging of ammeters mentioned by the author is at any rate in part due to the frequency of the stator current pulsations corresponding to the natural period of the instrument, causing resonance or "hunting" between instrument and pulsations, the swing being thereby amplified. The excessive stator currents mentioned, which I also have noticed, are doubtless due to the fact that the unbalanced rotor conditions almost totally destroy the motor torque, and then the motor, in the endeavour to cope with the load, takes an excessive stator current. The author mentions a method developed by Mr. Fox for calculating the sections for unbalanced three-phase rotor resistances; this method I was using about 10 years ago, and I find that we had stepping and capacity (expressed in percentages) standardized for controller resistances in 1911 and for starter resistances in 1913. The method was also published about 1916 on pages 186, 187 and 188 of the previously mentioned book.

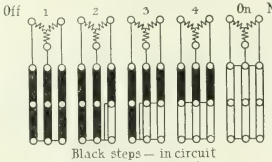

FIG. A.—Two-step, three-phase starting resistance; cutting-out of steps with 5 starter notches.

(*Communicated*): It was found from practical tests with motors, that if the ratio of the resistance in the phase having the highest value to that in the phase having the lowest value exceeded a certain figure, the motor when on load fell out of step or would not accelerate, and an excessive stator current was taken. This figure varies with different motors, but is of the order of from 2·5 for large motors to 4 for small motors. If, then, this figure is denoted by k^2 and the resistance of each phase of the rotor by r, the steps last cut out in each phase may have a value as high as kr, k^2r, and k^3r respectively, without detriment to the performance of the motor, when the steps in each phase are cut out separately. It is, however, very common in starting and controlling resistances (especially with drum-type controllers) to cut out the last step in all three phases simultaneously, under which conditions the steps in the 3 phases might have the same values as above but the kick of stator current on cutting them out would be 3 times as great as that on cutting out a step in one phase having only their mean value. As an example, a resistance designed thus for starting a small motor may have only 2 steps in each phase, and thus give 4 starting notches, the first step in each phase being cut out singly, and the second steps being cut out simultaneously. Fig. A shows clearly this arrangement, and

* "Electricity," vol. 3, Reference Library of the Bennett College, Sheffield.

Fig. B shows in vectorial form the magnitude of the resistances in the phases if corresponding equal steps were taken in each phase, the small inner circle representing rotor resistance, the next circle defining starting step 2 in each phase, and the outer circle starting step 1. If R is the resistance per phase allowing full-load rotor current to flow, the resistance per phase of the rotor winding and connections is, say, $0{\cdot}06R$ (6 per cent slip), represented by the vectors on the small inner circle. Step 2 of starting resistance on phases A, B and C may be taken to be, say, $0{\cdot}12R$. Deducting rotor ($0{\cdot}06R$) and step 2 ($0{\cdot}12R$) from $1{\cdot}00R$ leaves $0{\cdot}82R$ as the value of step 1 in all phases. Thus we have :—

Outer circle to next circle = Step 1 = $0{\cdot}82R$
Next circle to inner circle = Step 2 = $0{\cdot}12R$
Inner circle = Rotor = $0{\cdot}06R$

If step 1 in phases A and B were cut out we should get in these phases $0{\cdot}12R + 0{\cdot}06R = 0{\cdot}18R$, while

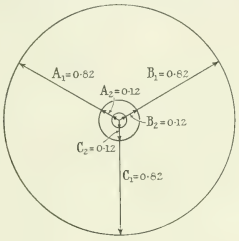

Fig. B.

in phase C we should get $0{\cdot}82R + 0{\cdot}12R + 0{\cdot}06R = 1{\cdot}00R$. The resistance in phase C would thus be $1{\cdot}00/0{\cdot}18 = 5{\cdot}55$ times the resistance in phases A and B, which would exceed the value for satisfactory working of the motor. The following table shows the condition on all the notches, Nos. 2 and 3 being badly unbalanced positions :—

Notch Number	Total Value of Resistance in Phase			Ratio of Max. to Min.
	A	B	C	
1	$1{\cdot}00R$	$1{\cdot}00R$	$1{\cdot}00R$	1·00
2	$0{\cdot}18R$	$1{\cdot}00R$	$1{\cdot}00R$	5·55
3	$0{\cdot}18R$	$0{\cdot}18R$	$1{\cdot}00R$	5·55
4	$0{\cdot}18R$	$0{\cdot}18R$	$0{\cdot}18R$	1·00
5	$0{\cdot}06R$	$0{\cdot}06R$	$0{\cdot}06R$	1·00

Fig. C illustrates the stepping method mentioned as developed by Mr. Fox, but independently developed and used by myself originally in 1911. The small central circle still represents rotor resistances, but instead of the step values being vectorially defined by circles, the values advance by a smooth spiral from phase to phase, and the following table shows values replacing those in the above table. It will be seen that the ratio between phases on all notches has been reduced to a uniform and lower value which will ensure successful operation of the motor.

Notch Number	Total Value of Resistance in Phase			Ratio of Max. to Min.
	A	B	C	
1	$1{\cdot}78R$	$1{\cdot}00R$	$0{\cdot}56R$	3·2
2	$0{\cdot}32R$	$1{\cdot}00R$	$0{\cdot}56R$	3·2
3	$0{\cdot}32R$	$0{\cdot}18R$	$0{\cdot}56R$	3·2
4	$0{\cdot}32R$	$0{\cdot}18R$	$0{\cdot}10R$	3·2
5	$0{\cdot}06R$	$0{\cdot}06R$	$0{\cdot}06R$	1·0

With r as the rotor resistance per phase, and k^2 the ratio as already defined, the general form represented

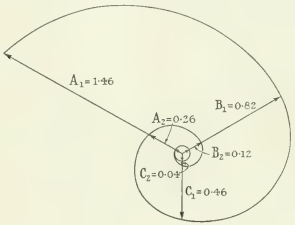

Fig. C.

by the spiral diagram, for two steps in each phase, is shown by the following table :—

Notch Number	Total Value of Resistance in Phase		
	A	B	C
1	k^6r	k^5r	k^4r
2	k^5r	k^5r	k^4r
3	k^3r	k^2r	k^4r
4	k^3r	k^2r	kr
5	r	r	r

The method may be applied to construct such tables and spiral diagrams of similar general form, for any number of steps. It is more fully explained in the previously mentioned book.

Dr. M. L. Kahn : The starting process as shown in Figs. 1 to 10, which demonstrate the different ways in which a starter may be used, can be realized only in actual practice if the operator has an indication when the starter handle should be moved. This can easily be provided by a rough current-indicator marked with red lines to show the limits or the stepping of the current. Such an instrument need consist only of a current coil

with a movable iron core, a balancing spring and the indicating needle. As each starter has to be rated for a certain current these instruments could be standardized and embodied in the starter case itself, thus making these an integral part of the starter. As it would be possible to use the starter in a correct way, it could probably be made with fewer steps if fitted with these indicators, and this saving would presumably pay for the indicators. In this way a reasonable use of the apparatus could be made easier without any addition to the cost. At present only a small percentage of starters are supplied with ammeters. This point has also some bearing on the rating of starters. As long as the current taken depends almost entirely on the operator, who has little indication whether he is using the apparatus correctly, a large safety factor is necessary, which explains the low figures of temperature-rise allowed at present as given on page 633. I agree with the author's remarks on the eddy-current starter, especially his criticism of the arrangement of insulated windings on the iron core. This type of starter corresponds to a transformer the secondary winding of which is connected to a resistance and reactance in series. The reactance expressed as a percentage of the rotor voltage is constant over the main part of the starting period, until the influence of the resistance-drop in the primary winding becomes predominant. This reactance reduces considerably the starting torque of the motor. The arrangement proposed by the author is equivalent to the eddy-current starter and has the same disadvantage that the rotor current flows through a circuit of high reactance at the beginning and during the major part of the starting period. This can be avoided by adopting instead a rheostat and a choking coil with laminated core in parallel, thus connecting the high resistance and the reactance in parallel instead of in series as in the two methods just mentioned. The choking coil can then be so dimensioned as to take comparatively small currents during the first part of the starting period, the bulk of the current flowing through the resistance. Towards the end of the starting period the percentage reactance of the choking coil falls as the flux in the core is decreased due to the increased influence of the resistance-drop in the winding of the choking coil. The current taken by the choking coil increases and becomes more and more a power current. The current in the rheostat falls proportionally to the rise in the motor speed, while the power current taken by the choking coil increases. The combination can be so dimensioned that the power current in the rotor circuit is kept more or less constant while the wattless current is considerably smaller than in the eddy-current starter. The reduction of the starting torque due to this current is therefore minimized. As the current in the choking coil winding is comparatively small during part of the starting period, while the losses in the iron core are reduced to a minimum by lamination, the temperature-rise of the windings of the choker can easily be kept within the limits allowed for insulated conductors without unduly increasing the size of the choker.

Mr. A. T. Bartlett: I am surprised that there is little or no reference in the paper to the effect of thermo-capacity in connection with the resistance material or units. This, of course, has a large influence on the rating, and the author has possibly purposely omitted reference to this phase of the subject. The tables giving particulars of the stored energy in motors and machines are of great value and show some important results. In Table 3, which refers to the effect of covering up the resistance units in various ways, it would be interesting to know whether the space between the iron covers and the resistance material was lagged, or whether it was simply an air space. The author remarked in his introduction that the corrugations on transformer tanks and the ribs on small internal-combustion engines were practically useless, and he apparently arrived at this conclusion from the results shown in Fig. 14. As, however, these oil-tank experiments do not appear to have been carried out until a uniform steady temperature had been reached, such a deduction is not justified, though no doubt the use of corrugation and ribs has been considerably overrated.

Mr. A. E. Angold: The author has given some useful figures relating to the various duties for which starters have to be designed, and outlines a very practical system of calculation by percentages of the duty required of any particular starter. It would have been instructive if he had expanded this scheme, and given a formula for determining the watt-seconds ratings of a line of starters in relation to, say, their linear dimensions, but apparently wire resistance units do not obey any simple formula. I do not understand why this should be so, and I think that many of the author's difficulties arose from attempting to measure temperature-rise by thermometers. All the electrical, heating and cooling characteristics of a line of auto-transformer starters, whether air- or oil-cooled, can be expressed as powers or roots of their linear dimensions. Temperature tests calculated on the rise of resistance of the copper are quite practical, and it is the temperature of the copper in contact with the cotton and oil which limits the duty of any such starter. In the same way, it is the temperature of the wire of a resistance starter which limits its duty, so that if we have a reliable method of measuring the temperature of the wire we could hope to set out the desired formula for ratings. The figures of temperature given by the author relate chiefly to the continuous rating. Naturally this must be so if measured by a thermometer, because it would be very difficult to apply a thermometer so that it does not take more heat from the wire than would have been radiated if the thermometer had not been there. Also, the amount of mercury and glass must be such that this same quantity of heat must raise their temperature to that of the wire. It would therefore seem that to determine ratings for intermittent use, temperatures must be calculated from rise of resistance. One way to do this on open spirals is to substitute during this test an iron wire of the same gauge and length and to regulate continuously the current passing through it to compensate for increase of resistance as the temperature rises, and so keep the watts constant, and also equal to the watts dissipated by the original spiral. Correction may have to be made for the different specific heats of the two metals, but even without this correction very useful comparisons can be made between one

starter and another of the same general proportions. If the same method be used for a wire wound in a spiral groove on a stoneware cylinder it may not be advisable to substitute iron wire when making the test unless it is known that the two wires have approximately the same coefficient of expansion. However, some resistance alloys have a quite measurable increase of resistance when raised to 500° F., and with such it would not be necessary to substitute iron wire during the test.

Mr. R. G. Jakeman: In the equation at the beginning of the paper the author designates the resistance which passes full-load current at normal line pressure by the figure **1**. It would seem more logical, however, to express it as 100 per cent resistance, and that term is used a little further on. In discussing starters for fans and centrifugal pumps, the author does not mention the case of a mine-ventilating fan with long air-passages. If the fan is brought up to speed quickly, it will be running at full speed before the air pressure has risen to its final value, with the result that the motor will be seriously overloaded. The motor must therefore be accelerated slowly, and the starter rated accordingly. The same remarks apply to a centrifugal pump, if it starts with the delivery pipe empty. In asking for particulars of the armature resistance from the motor makers, it is necessary also to obtain the resistances of the interpole and compensating windings. With regard to the eddy-current controller, an article by Rüdenberg on the use of a transformer and resistance in the rotor circuit was published in the *Elektrotechnische Zeitschrift* a few years ago, and an abstract appeared in the *Electrician*.* The author states that the resistance-drop in an auto-transformer starter is of little consequence, but the greater the resistance the higher the current taken from the line for a given torque. With a rheostatic starter, if 50 per cent current is required in the motor, the same current must be taken from the line, whilst with a pure auto-transformer starter only 25 per cent is taken from the line. The use of unequal tappings on the phases of an auto-transformer does not appear to be necessary, since such fine adjustment is seldom required. It would be interesting if the author would add a comparison of the auto-transformer with only two coils connected in open delta. I am particularly interested in the Appendix. The treatment of unequal rotor resistances by means of ordinary vector diagrams is very complicated, but this method gives the result with very little trouble. It would be useful if the author would give the reference to Field's work.

Mr. J. Anderson (*in reply*): Mr. Wilson stated that the peak value of the current-rush actually obtained is two-thirds of the calculated value. The current will depend, however, on whether the motor is series or shunt wound.

In reply to Mr. Line, intermittent ratings can be calculated, but this is not so easy as it seems, and the data regarding brake magnets were introduced with a view to illustrating the difficulties which arise with such a simple piece of gear as a bobbin and a mass of iron. I do not consider the swinging noted in connection with Table **4** to be due to synchronism of the current frequency and the natural periodic time of the instrument movement, because a relay in the rotor circuit consisting of a bobbin and a plunger $\frac{5}{16}$ inch diameter and about 3 inches long, set for 200 per cent full-load current, operated when swinging was observed, showing that a current at least equal, at the peaks, to 200 per cent full-load current was actually flowing although the motor was on light load.

I agree with Dr. Kahn that if the time is relatively long, say anything over 30 seconds, it is not difficult to cut out the resistance at the correct speed, particularly if the ammeter is marked as suggested on page 625. It can be done sufficiently accurately with regular acceleration by listening to the motor and moving the switch from step to step when the sound indicates that acceleration has ceased.

Mr. Bartlett referred to the advantage of thermal storage on short ratings. I agree that this is advantageous and that very high capacities can be obtained, but it is difficult to make the connections in a satisfactory manner. In regard to Table 3, the particulars of the enclosures are given in the paper. There was no lagging and many hundreds of tests lasting 6 hours each have been made, so that the steady state was attained with wires of all diameters up to No. 11, and there is little doubt regarding the accuracy of the tests.

In reply to Mr. Angold, the measurement of temperatures by means of a thermometer is standard practice and is recommended by the B.E.S.A., and as all tests were continued for many hours there is no doubt that the thermometers gave sufficiently accurate results

Mr. Jakeman asked for particulars of the out-of-balance with closed and open delta auto-transformers. I prefer to use three-limb star-connected transformers so as to avoid out-of-balance effects, although it makes the switchgear more expensive. Mr. M. B. Field's paper on "The Potential of Partially Insulated Systems in relation to the Potential of Earth" was published in the *Journal*, 1908, vol. 41, page 200.

[The London and Newcastle discussions on Mr. Anderson's paper will be found on pages 646 and 652 respectively.]

* *Electrician*, 1919, vol. 83, p. 422.

DISCUSSION ON "STARTERS."*

At The Institution, 2 March, 1922.

Mr. J. M. L. Slater: Some valuable information with regard to the starting torques with different classes of apparatus is given in Table 2 of Mr. Anderson's paper. As far as my observations go, the figures given are correct except in the case of item 20 (air compressors). The figure given is 6 per cent. I have some figures with regard to compressors, taken from the catalogue of a very reputable firm, in which they state that by closing a compressor intake the power necessary to drive it is reduced to from 15 to 20 per cent of full load. I have generally found that these figures are rather on the low side. Perhaps Mr. Anderson has in mind some special method of unloading the compressor, and it would be interesting to know the particular method which he has in view. With regard to Fig. 11, I think that many of the inconsistencies in the results might be obviated by using a thermo-couple for measuring the temperature. Unless a thermo-couple is used in measuring the temperature of small wires, the comparatively large mass of the thermometer against the wire must give rise to considerable variation in the temperature reading. It would be interesting if the experiments were repeated and the measurements taken by thermo-couples. On page 633 reference is made to the temperature-rise of materials, and the suggestion is made that this should be increased from 600 to 700 degrees F. This figure is, I think, quite satisfactory if the correct material is used for resistance. Cupro-nickel is not satisfactory at temperatures over 300° C. (572° F.), and if higher temperatures are to be worked at it is necessary to employ the nickel-chromium group, which permits of temperatures up to 1 000° C. (1 860° F.) being used. I cannot understand the heading of col. 5 of Table 6.

On page 198 of Mr. Wilson's paper, reference is made to three electrolytes, viz. washing soda, salt and caustic soda. In general I have found washing soda to be the best. Salt creeps badly. I have had experience of two other electrolytes, viz. potash alum and potassium bichromate. Some colliery engineers prefer the first because it gives better control at low speeds. At one colliery the engineer favoured the latter for the same reason. I have had very good results with these two over a long period, and it would be interesting to know whether Mr. Wilson has had satisfactory results or has tried potash alum. With regard to the method of calculation given on page 202, no allowance appears to be made for variation in the form of starter. For example, with the types shown by Figs. 6 and 7, when the electrodes are first immersed the current passes through the small amount of solution at the top of the tank and the under layers are heated up in succession as the electrodes are lowered into the liquid. This must lead to the solution being at different temperatures in different parts, and if the maximum temperature were measured the power absorbed would vary, depending on the type of starter. In the case of the type of starter shown in Fig. 10 the whole of the liquid in the pots and above is heated uniformly from the bottom. Mr. Anderson referred to a similar point in connection with Fig. 14 of his paper. For this reason, one would anticipate that in the results given under the heading of "Calculations for Rating" the maximum temperature—not the average temperature—would not be kept within the limit stated. It appears to me to be necessary with the type of starter shown in Fig. 6 to make an experimental model and determine the amount of power it will absorb, which would give a constant applicable to all starters of the same design. In connection with the remarks on page 205 referring to the form of electrodes employed in Fig. 10, one would imagine that if two flat electrodes as shown were brought into contact, a very great jump in speed and current would result at that moment.

Mr. T. Carter: Mr. Anderson's paper is, in my view, an excellent example of standardization on the best possible lines, working everything out, as it does, from first principles and using as an aid carefully determined experimental results. A paper* by Mr. A. E. Gott dealt very fully with the grading of the steps in a geometrical series, and pointed out that too high a potential difference between successive contacts sometimes made that sort of grading impracticable, and might even necessitate the use of additional steps to prevent sparking. Mr. Gott was not the first to publish the principle of geometrical grading for starters—I think Pochin did it much earlier—but he worked it out in a way that was new and useful at the time, and I think he is to be regarded as at least a semi-pioneer. I gather from his paper that Mr. Anderson would have no off-contact on starters, and I agree with this view; a circuit breaker or a switch ought always to be provided to break the circuit. I would draw special attention to Mr. Anderson's excellent principle that when many of the data are open to doubt, extreme accuracy in calculations based on them is merely a waste of time; this is a counsel of sanity that is often forgotten, as is also the recommendation to understand what rules mean before applying them. The paper draws attention usefully to certain possible difficulties in the use of eddy-current starters; their value is occasionally discounted by want of complete foresight in their application. I am sorry to find Mr. Anderson so pessimistic about the furnishing of data by manufacturers of motors; as one of them, I would say that it is perhaps better to be cautious than to be wrong, and that I have even known an instance of a starter-maker giving information about what certain starters would do that was in the highest degree misleading. Non-technical buyers of starters are naturally unable to give full particulars of the torques and other characteristics of the drives in which they are interested, and Mr. Anderson's informa-

* Papers by Mr. J. Anderson (see page 619) and Mr. W. Wilson (see page 196).

* "Starting Resistances," *Journal I.E.E.*, 1902, vol. 31, p. 1219.

tion is therefore bound to be of the greatest possible value to the industry.

Coming now to Mr. Wilson's paper, I think a very useful point in favour of liquid starters as compared with metallic resistance starters is that an overload on the former shows its results by the boiling of the liquid, whereas with a wire starter eventual disintegration of the material takes place, often without previous warning, and renewals are obviously much more difficult than when only the addition of water to a tank is required. I should like Mr. Wilson to say whether, and if so how much, the specific heat of the liquid is altered from unity by the addition of the soda or whatever is used; his calculation is based on the specific heat of water, and I assume therefore that the difference is slight. Liquid starters are very serviceable pieces of apparatus; if trouble occurs in them it is usually due to ignorance and neglect on the part of their users, who sometimes omit to put in the liquid, and sometimes the soda. Perhaps manufacturers of liquid starters are to blame because they do not issue instructions in easily understood language; it is usual to specify a 10 per cent solution of washing soda, but it would perhaps be better to say that one pound of soda must be used for every gallon of water. I would emphasize Mr. Wilson's reference to the very important point that many starters have been designed in the past on the assumption that they absorb the whole of the energy at starting, whereas they actually absorb only half. I hope that all possible steps will be taken to make this clear, because the misunderstanding has caused starters to be supplied that are too large and that are consequently unnecessarily expensive. I would also commend Mr. Wilson's suggested specification for the rating of liquid starters on the basis of successive starts with a long cooling period following each of them, as preferable to the alternative proposal sometimes made that they should be tested on the basis of starts rapidly succeeding each other. Mr. Wilson's specification is more nearly in accord with working requirements than the other which, because of the rapid succession of starts, involves a practically unnecessary reduction of the horse-power-minutes involved in each start, and so leads to an undesirable increase in the size and cost of liquid starters. Mr. Wilson's specification is safe because even if the liquid starter is called upon to deal with a rapid succession of starts in an emergency the only result will be to boil the liquid. The use of liquid starters is to be encouraged because of their many advantages, and Mr. Wilson's rating would under all ordinary circumstances lead to the choice of a starter neither unduly small nor unduly expensive, and therefore eminently suitable for its work.

Mr. J. R. Blaikie: With reference to Mr. Anderson's paper, and the curious heating effects with high temperature peak in the middle of the elements shown in Fig. 11, the phenomenon may possibly be due to the electrostatic state of the element. I think it is generally known that in making tubular electric condensers there is a higher electrostatic strain in the ends of the tubes than there is at the centre. In that case, in the series of elements which Mr. Anderson showed, it is quite possible that the top one of the six is nearer to earth potential than the bottom one; and the difference in temperature between the centre and the two ends is very considerably less. We know that there is a great deal of dust-bombardment effect with quite low potentials, as seen in direct-current work where, if there are two conductors mounted on white insulators, one pole gets dirty while the other remains white. It is quite possible, therefore, that this dust-bombardment effect disturbs the convection currents and alters the rate of cooling. There is another suggestion I should like to offer which might help in the investigation of convection currents. If one allows a naked arc, or strong ray of sunlight, to cast a shadow of a hot element on to a screen, the convection currents can quite easily be seen. That is probably due to the refraction of the light at different temperatures of air, or possibly to the absence of dust from the air. Kelvin performed an experiment with a red-hot cannon ball, and found a dark zone round the ball which he attributed to the absence of dust. Bombardment or dustless zones might very seriously interfere with convection currents and produce this extraordinary result.

With reference to Mr. Wilson's paper, I should like to ask the author if he feels satisfied that the experiments which he has made on the small apparatus, with submerged electrodes, and the data obtained, would be applicable to many other types where the greater part of the action takes place on the surface. The case of steam or gas generation under hydrostatic pressure might greatly reduce the possibility of arcing across, by keeping the bubbles small and allowing them to rise vertically at a high speed. In other cases where the electrolyte is flooded up, the major part of the action takes place on the surface and the liquid produces big bubbles of steam and gases; consequently there is more tendency to flash over. With regard to the question of the different substances which may be used for the electrolyte, I have found a novel one in the American "Handbook of Electrical Engineering," namely, sodium sulphate. I do not know what are the advantages of these various substances. The "Handbook" to which I have referred gives the same nomenclature: sulphuric acid, 1 inch; potassium hydrate, 0·8 inch; sodium chloride, 0·3 inch; sodium sulphate, 0·18 inch and copper sulphate 0·1 inch. The potassium hydrate is exactly the same as Mr. Wilson's sodium hydrate.

Mr. H. Brazil: It is interesting to note the difference between the papers by Mr. Anderson and Mr. Wilson, particularly with regard to the material used for the resistances. Mr. Anderson, who deals with the smaller machines and requires very exact regulation, employs a wire having a negligible temperature coefficient, whereas Mr. Wilson, concerned with very much larger loads, is compelled to use a liquid having a very considerable negative temperature coefficient. On page 208 Mr. Wilson details the troubles that occur with liquid rheostats, particularly when direct current is used: electrolysis takes place and gas is given off; the anodes wear away rapidly and require replacing and the solution deteriorates and requires renewing from time to time. It occurred to me that it might improve the apparatus considerably if another material

were substituted for the liquid—something which would have the good qualities of a solid without its liability to fracture and to break circuit and yet possess the property of a liquid in that it would flow and thus dispense with contact stops without the disadvantage of boiling at a comparatively low temperature. The substance I suggest is carbon powder, and I have taken some rough tests with some powder in an ordinary pail by pushing a thin metal sheet downwards into the centre of the pail. I found that the current increased steadily from 0 to 300 amperes at 80 volts, the powder behaving very satisfactorily. With regard to the capacity for absorbing power of the two substances, liquid and powder, Mr. Wilson gives 200° F. as a limit of temperature for the liquid, whereas the powder may be raised to a temperature of nearly 2 000° F. without being damaged. The paper gives 3 h.p.-minutes per pint as the rating of the liquid, but I am in possession of figures which show that the powder could be rated up to 15 h.p.-minutes per pint. Carbon powder being an inert substance which does not oxidize, no corrosion of the anode and the containing vessel takes place, and the troubles due to boiling, electrolysis and the production of gas are entirely avoided. I suggest, therefore, that in those cases where rheostats are required to deal with large amounts of power for short periods, and particularly on electric locomotives, the use of carbon powder instead of liquid might profitably be considered by designing engineers.

Mr. H. C. Hastings (*communicated*): On page 626 Mr. Anderson mentions automatic contactor equipments and refers to the relative merits of current relays and pressure relays connected across the armature for controlling the closing of the contactors. He appears to convey the impression that there is very little to choose between the two systems. I think, however, that the pressure-relay method, generally known as the counter E.M.F. system, has long been recognized as unsatisfactory for general use. That this is so can be readily shown, and Fig. 1 may be used conveniently for the purpose. This diagram apparently refers to a shunt-wound machine and a 7-notch starter, the armature current being allowed to decrease to the same value on each step before notching. The induced armature volts on each step at the instant before notching will be approximately proportional to the speed of the armature, and it will be seen that there is very little difference between the speeds corresponding to notches 5, 6 and 7, the difference between the speeds for notch 6 and notch 7 being less than 5 per cent. If pressure relays were used for controlling the closing of the contactors the relay for notch 6 would have to be set within 5 per cent of that for notch 7, so that a variation of 5 per cent in the operation of relay 7, if this were on the low side, would cause it to operate at the same time as notch 6, and the current peak would be double the normal value. If, on the other hand, a current relay had been used, the 5 per cent variation in the operation would cause only a 5 per cent difference in the current peak. This is evident, since if C_s is the value of current at the instant before notching, and C_p the instantaneous value of current after notching, the relation between C_s and C_p is $C_p = C_s\ (R_n/R_{n-1})$, where R_n is the total resistance in circuit before notching and R_{n-1} the resistance after notching. This assumes that there is no series winding, and that the effect of the self-induction of the armature is negligible, which is generally the case. Thus, a 5 per cent change in C_s will give a 5 per cent change in C_p. Not only is the counter E.M.F. system of control more sensitive to error in the operation of the relays, but the relays themselves are more liable to error, since shunt coils are used, and the current in these will vary with the temperature, whereas this is not the case with the series coils of the current-limit scheme. Another disadvantage of the counter E.M.F. scheme is that it is suitable only for one line voltage without re-adjustment, as the relays are set to operate at a predetermined voltage. If the line voltage varies considerably, as in the case of many steel works, it is necessary to set the relays to correspond to the highest voltage, otherwise there will be a very high peak of current when closing the last contactor, but on low line-voltage this may result in the pressure not being high enough to close the last relay and contactor. A reference to the diagram will show that there is not the same disadvantage in using the counter E.M.F. scheme for the first notches. The scheme can be used satisfactorily where the motor is to be started against little friction and inertia load, and is generally applied to machine-tool control, where only one division of resistance is used, and where the current may be allowed to drop to 25 or 30 per cent of full-load value after switching on, before cutting out resistance. A reference to Mr. Anderson's Tables 1 and 2 will show that even under these conditions the motors will start up in 2 or 3 seconds if the current on the first notch and the maximum peak current are in accordance with the maximum allowed by the B.E.S.A. Specification. Automatic control schemes are in use where the contactors are controlled by relays having shunt coils connected across part of the starting resistance. As the current in these coils depends upon the current in the armature and starting resistance the scheme is not open to the same objections as the pressure scheme referred to above, where the action of the relays depends upon the voltage across the armature. On page 636 Mr. Anderson refers to the interesting and comparatively recent development of the so-called eddy-current starter. These have been used to a limited extent for the control of motors driving "live" rolls in steel works. The results of the few tests I have made indicate, as one would expect, that the torque per ampere from the line is less than would be obtained with resistance control, that the maximum torque which can be obtained is less, due to additional reactance in the rotor circuit, and that consequently a larger motor would be required for the same limiting service conditions. Generally speaking, a slow operation would result for reversing equipments with this form of control, and an increase in the capacity of the motor, unless this is obtained without increasing the moment of inertia of the rotor, will not increase the speed of reversal in proportion to the increase in the rating, for service conditions where the principal energy con-

sumption is devoted to reversing the rotor of the machine. To obtain conditions equivalent to starting with non-inductive resistance in the rotor, controlled by current-limit relays, a device is required, the effective resistance of which will decrease directly with the slip, and which will not introduce into the rotor the same effect as reactance. As Mr. Anderson points out, the eddy-current starters at present made do not entirely comply with these conditions. Assuming that with the slip-rings short-circuited the slip is 4 per cent at full-load current, the resistance required with the motor at rest to reduce the current in the line to full-load value will be approximately 25 times the rotor resistance. Good results would be obtained if the effective resistance in the rotor circuit automatically decreased from this value to, say, twice the rotor resistance as the rotor frequency decreased due to the motor speed increasing. The tests I have made on one particular set used with "live" rolls show that the effective impedance of the eddy-current starter was such that with full-load torque the speed of the motor would not increase beyond two-thirds normal speed if the line current with the motor at rest were $1\frac{3}{4}$ times the full-load value. In this case the result was equivalent to leaving permanently in the rotor circuit a resistance which would decrease the speed to two-thirds the normal at full-load torque. In order to reach full speed without excessive peaks in the line under these conditions, at least two contactor notches would be required for cutting out the eddy-current starter. Many methods of starting slip-ring motors automatically without switches in the rotor circuit were proposed in the early days of induction motors between 1898 and 1900. Mr. H. M. Hobart proposed the use of wrought-iron bars of such section that, due to the skin effect, the resistance would decrease as the frequency in the rotor decreased. Resistance materials having negative temperature coefficients have also been used, but the objection to these is that after one start it is necessary to wait until the material has cooled. Mr. Anderson has referred to the method of controlling a.c. slip-ring motors by cutting out resistance unequally from the rotor circuits. This has been common practice ever since cranes have been operated electrically. The advantage is that for any particular number of speed-control points fewer contacts are required in the controller and fewer leads between controller and resistances. Mr. Anderson has covered a wide range of subjects, and apparently he does not differentiate between starters and controllers according to the B.E.S.A. definitions, as in one part of the paper he refers to the control of cranes and haulages, which should rightly come under the heading of "Controlling Devices." This leads to a little confusion, as for instance on page 628 he refers to the breaking capacity of the starter from notch to notch, and from the first notch to the "off" position, as being an important feature in the design, whereas on page 629 he points out that the circuit should not be broken on the starter. Where the conditions are such that the motor starts infrequently it is common practice to use the face-plate starter, and in order to save expense the starter element is usually not arranged for opening the circuit except where the starter arm flies back to the "off" position in case of low voltage or overload. Starters of this type are in general not suitable for notching back towards the "off" position by hand. Where starters of the drum type are used, built on the same lines as those used for controlling crane motors, the designs are generally such that notching back from step to step and to the "off" position is permissible without detriment to the starter.

Mr. W. E. M. Ayres (*communicated*): In connection with the section allotted to liquid slip-regulators in Mr. Wilson's paper, there is considerable prominence given to the supposed "sluggishness of action" due to inertia in the moving parts. I am at a loss to understand how this fallacy continues to exist. The induction motor of an Ilgner set, supplied with constant voltage, has its load and current determined by the speed of the flywheel and the rotor resistance. As the latter is controlled by the current through a torque motor it follows that the current must first alter. But the current can alter only by variation in the flywheel speed. We see, therefore, that the slip-regulator (if of the balanced type as described) is required to operate only at the rate of change of speed of the flywheel. In an actual case where the overload torque on a motor-generator set is 5 times the full-load torque, i.e. 4 times the motor output to be supplied from the flywheel would reduce the flywheel speed 10 per cent in 3 seconds, an excess torque on the servo motor of 2 per cent is required to enable the dippers to follow the load at the necessary speed. This represents an increase in current of only 1 per cent. The armature of the torque motor is usually mounted on ball-bearings, and the dippers and counterweight are supported on knife-edges. The torque motor exerts about 30 lb.-ft. at full current, so that the solid friction is approximately 1 per cent. What might be termed the "frictional backlash" of the combination is easily kept within $\pm$ 2 per cent. Recording ammeter charts show this to be the case by the small hump where the regulator comes into operation and the small depression where it ceases to function. That the slip-regulator does function properly is proved by the fact that in many cases the substitution of a slip-regulator for a permanent slip-resistance has reduced the motor heating without lessening the output from the rolls. For short passes with long periods between passes, however, they have so little to do and the gain in efficiency is so slight that the expense is not justified. These remarks do not refer to contactor-type slip-regulators, which are not reviewed in Mr. Wilson's paper.

Mr. N. G. Langrish (*communicated*): On page 623 Mr. Anderson gives a formula for the time to accelerate a motor, and apparently the value of T is the percentage constant torque, in excess of the load, that would speed up the motor in the same time as the variable torque obtained by the use of a step-by-step starter. If this is so it appears that the value of K should be 0·5, but in the paper it is stated that this value may be conveniently taken as 0·5. On page 628 it is stated: "In Fig. 6 the peaks and valleys are the same, giving 8·3 per cent effective torque." From the

figure it appears that the minimum starting torque is 66·6 per cent of full-load torque and the load 10 per cent of full-load torque, so that the minimum effective torque for accelerating purposes is apparently 56·6 per cent and the mean will be considerably higher. To what does this figure of 8·3 per cent actually refer? In the above the effect of the last step is neglected, as in the paper. In a number of instances the watts per square inch of radiating surface of the wire are mentioned as being a determining factor in the temperature-rise. It should be clearly pointed out that for continuous ratings of wires freely suspended in still air the watts per square inch increase as the diameter of the wire decreases, for a given temperature-rise. The same holds good for wires carrying current under oil. When the wire is wound on an earthenware or other support, the latter, being in contact with the wire, conducts some of the heat away to other parts of the insulator and the surface of the support becomes an additional radiating surface and, while this to a certain extent complicates matters, similar results are obtained as with the wires freely suspended in air. For short ratings where the resistance units are not wound on supports and the whole of the material is active, provided that the continuous ratings of the material are known for a number of temperature-rises, the short ratings can be fairly accurately calculated from the formula

$$T_t = T_f(1 - e^{-Wt/K})$$

where T_t = the temperature-rise after t seconds;
T_f = the temperature-rise if left on continuously with the same load in watts on the unit;
e = the base of Napierian logarithms;
W = the watts lost per degree C. rise above the ambient air, due to radiation and conduction; and
K = the watt-seconds to heat the body 1 degree C.

When the wire is wound on a support the conduction of heat by the support complicates matters and renders a series of tests necessary, although for short ratings up to 10 seconds it has been found that the effect of the porcelain is very small and that sufficiently accurate results are obtained by calculations based on the thermal capacity of the wire itself. Most of the heat tests in the paper appear to have been taken with the help of a thermometer for measuring the temperature-rise, and it is suggested that in many cases a thermometer gives unreliable results. Some tests of this nature were recently carried out on units somewhat similar to those mentioned in the paper and the temperature-rise was measured by thermometer and also by the resistance method. For the purpose of this latter test the units were wound with copper wire and the input measured by a wattmeter and kept constant by means of a series regulator giving fine adjustment. The resistance of the unit was obtained from readings of a voltmeter and ammeter connected in the circuit. It was found that, although the resistance method gave only mean temperatures and the thermometer was placed in what had been found to be the hottest point of the unit, for short ratings the thermometer readings were much lower than the temperature-rises measured by the other method and were not consistent; even with continuous ratings, although the readings did agree rather more nearly, the differences that were found to exist were not consistent. The curves given in Fig. 11 are most interesting, but it must not be taken as a general rule that to mount resistance units in tiers does not affect their rating. Tests taken at the Metropolitan-Vickers works some few years ago on resistance frames mounted one on top of the other gave a considerable difference in the temperature-rises in the different tiers. It was found that with four frames mounted in this way, to obtain the same temperature-rise on each of the banks the watts per grid had to vary from 120 for the bottom row to 112 for the second, 106 for the third, and 100 for the top row. Providing the mounting is such that the air can freely rise through all the tiers, it appears that the upper banks must be surrounded by air heated up to a certain extent by the lower ones, and therefore for the same temperature-rise they must be able to dissipate less heat.

Mr. F. P. Sexton (*communicated*): The early part of Mr. Wilson's paper does not make it clear whether by "surface resistance" (see page 200) is meant an actual surface resistance or the E.M.F. due to contact of metal and liquid. If the latter, the author is in error, for the contact E.M.F. has been repeatedly determined. The curve shown in Fig. 4 does not prove this point, for if the potential difference is given by an expression $E = I(R_1 + R_2)$ it can be seen that the curve will be linear whether the value of R_1 be zero or some other value, since the current I was kept constant. Here R_1 is taken as the resistance additional to that of the liquid. The same remark applies to the expression $E = 2e - Irl$, where E is the E.M.F. over the liquid resistance, $2e$ the total contact difference of potential over the electrodes, r the resistance per unit length, l the length, and I the current. This equation should give the potential over the resistance for any condition, and would certainly be linear. Hence there is no reason why the difference of potential of 3 volts shown in Fig. 4 should not be due to a surface resistance or contact potential, or both, and not entirely to resistance of the leads as stated. I have no figures for the iron-sodium chloride solution E.M.F., but it would be from 0·25 to 0·6 volt or in that neighbourhood and hence not sufficient to account for the whole potential difference observed. Taking the figures from the curve of 18 volts per inch length and with a current density of 540 amperes per sq. ft., the conductivity is 0·68 ohm per cm^3. This value can be compared with the value given by Kohlrausch and Grotrian in 1875, as

$$\lambda_0 = 0{\cdot}0412 \times 10^{-9}(1 + 2{\cdot}95 \times 10^{-2}\theta + 8{\cdot}6 \times 10^{-5}\theta^2)$$

or at 18° C. this becomes 0·0671 × 10^{-9} in mhos per cm for a 5 per cent solution. The difference is in a large measure due to the temperature of the author's electrolyte, which is unfortunately not given.

Mr. J. Anderson (*in reply*): With reference to Mr. Slater's remarks, the air compressor figure given in Table 2 was obtained from tests on two 150-h.p. compressors fitted with a by-pass, but the exact arrangement was not noted. A thermometer should give sufficiently accurate results for continuous-rating

tests extending over 6 hours, as in the case of those described in the paper. Table 6 was intended to show the effect of unequal tap voltage in giving an average torque which is in excess of the torque to be expected from the lowest tap voltage. Thus, if the three taps are 0·5, 0·5 and 0·5, the torque is 25 per cent; but if they are 0·5, 0·6 and 0·75, the torque is 34·8 per cent, which is very nearly equal to the 36 per cent obtained with three taps of 0·6, 0·6 and 0·6.

I agree with Mr. Hastings that the current relay is preferable for general use and this opinion is indicated in the first two paragraphs on page 628 of the paper. As regards "eddy-current starters," I agree that more rapid reversals can be obtained with resistance control. Mr. Hastings mentions the apparent confusion between starters and controllers, but any starter may be used as a controller if operated improperly, and this possibility of improper operation has to be kept in mind and allowed for as far as practicable.

Mr. Langrish refers to the formula on page 628. The value of K is generally 0·5, but there are starting conditions where it has another value, hence the use of the qualifying phrase to which he objects. The minimum effective accelerating torque is 56·6 per cent as Mr. Langrish states, and the figure of 8·3 per cent is the average of the saw teeth, making the average effective accelerating torque 64·9 per cent as given in the paper. Mr. Langrish also refers to the heating of wires in air. The temperature-rise should be proportioned to i^2/d^3, where i is the current and d is the diameter of the wire. Actually the ratio is more nearly $i^{1\cdot4}/d^{1\cdot05}$. This means that a small wire is more effective than a large one in dissipating energy. When wires are wound on stoneware cylinders they behave as if they were flat strips of equal width and varying thickness, and the dissipation in watts per cylinder for a given temperature is nearly constant throughout a large range. As the heating periods get shorter the effect of the support decreases, but even for heating periods of 15 seconds it is still considerable. It is very difficult to determine the influence of the support for short ratings on continued cycles of heating and cooling.

Mr. W. Wilson *(in reply)*: A number of speakers in the discussion have amplified portions of my paper and have contributed additional information, which I have found very interesting and for which I am grateful.

The curves in Fig. 14 (page 209) were intended to include the various substances commonly used as electrolytes. To these Mr. Slater has added two, potash alum and potassium bichromate, neither of which I had previously encountered. The latter I should regard as too poisonous and corrosive for safe use; but the former should form a satisfactory electrolyte lacking the corrosive effects of common salt on iron, and of washing soda on insulating materials. I have already made a preliminary test upon this substance, and find it performs quite well. Its conductivity curve lies just below that of washing soda in Fig. 14.

Mr. Brazil has proposed the use of carbon powder instead of a liquid, and it certainly seems likely that a practicable and useful piece of apparatus could be designed on these lines. One objection would appear to be the combustible nature of carbon, and another its mechanical resistance to the insertion of any but edge-wise or pointed-rod conductors. I hope, however, to make up and test a rheostat of this form in the near future.

The expression "surface resistance" was taken from an article on liquid rheostat design, in which the statement was made that "the surface contact resistance is the governing factor, for the same electrode surface passes practically the same current, whether the plates are 5 or 50 feet apart." Without seeking to define the exact meaning of this, I carried out the test on page 200 in order to test the statement generally. If it were true, the curve obtained should have been a line nearly parallel with the co-ordinate representing the spacing. If, on the other hand, the curve not only were rectilinear but passed nearly through the origin, then it could be assumed that the component in question, whatever it might consist of, was negligible. The temperature of the liquid in Fig. 3 was not permanently recorded, but was maintained constant at a definite point somewhere between 70° and 80° F.

With regard to unequal heating of the liquid in the dipper pattern, shown in Figs. 6 and 7, there is no doubt that this occurs to some extent; but in an apparatus of this shape and construction the temperature is quickly equalized by conduction through the water and the metal during the period of rest following the starting operation. The "jump" in voltage when final contact is made between the plates is frequently mentioned as a prevalent defect of the apparatus. I have availed myself of the extensive organization of an electrical firm to check this allegation, besides drawing upon my own experience. The result has been to discover not a single case where this "jump" has not been due directly to the use of too weak an electrolyte, and has not been immediately removed by making up the solution to the correct strength. The type shown in Fig. 10 is an especially favourable design in this respect, as the resistance, and therefore the voltage-drop at a given current, vary directly with the spacing. Thus the voltage drop at $\frac{1}{8}$-inch spacing will be 1/160 of that at 20 inches, provided the resistance of the solution permits the normal motor current to flow at the beginning of the operation. It will be seen that this fraction leaves no room for any appreciable jump in voltage, and therefore jumps in current and speed are alike put out of court.

In reply to Mr. Carter, the specific heat of solutions below about 10 per cent is very little less than unity, and they were assumed to have this value in my calculations. To give an actual example, however, the specific heat of a 10 per cent solution of washing soda is about 0·98. I agree with this speaker's comments regarding instructions for making up the electrolyte. In addition to lack of clearness to the untrained person, there is some ambiguity in the percentage rule, since a 10 per cent solution may be made by weight or by volume. In the former the solution contains one part of solid to only nine parts of liquid, while it is practically one to ten if made up by volume of liquid, and it will therefore be seen that there is a possibility of appreciable

error if instructions are not made precise. In making up the solutions for Fig. 14, it was borne in mind that the cubical contents of a rheostat tank are known, and that the most convenient method of mixing the electrolyte would be to insert the requisite weight of solid, in the form of a strong solution, before the tank is full. Water would then be added to fill the tank to the standard height. Thus 10 per cent in Fig. 14 means one pound in every gallon of the resultant solution.

The above may explain some of the discrepancy observed by Mr. Blaikie between Fig. 14 and the curves reproduced in various handbooks. The latter curves

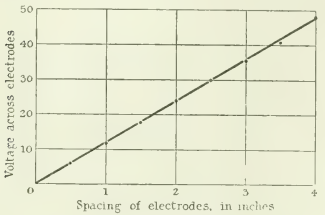

FIG. A.—Curve showing variation of potential with spacing.

are apparently obtained by calculation, the percentages being arrived at by weight, the various chemicals being pure, and the resistances derived in the first place by bridge measurements. My curves were obtained in an actual rheostat specially made for this test, by measuring the current and fall of potential due to the passage of an alternating current at 50 periods and the ordinary commercial chemicals were used throughout. Thus, practical conditions have been reproduced, and the results should be those required for practical purposes. I have dealt with the effect of surface action in my remarks on page 215.

Mr. Ayres has apparently been unable to discriminate between criticism and condemnation. His reference to the ball-bearings and knife-edges employed to minimize that portion of the sluggishness due to friction would seem to indicate that the "fallacy" is rather an urgent truth. He has quoted an assortment of data to prove that in a particular case the dippers could follow the load at the necessary speed; but it should be remembered that, whereas the load may be imposed suddenly, the "necessary" speed can be attained only after a number of usually heavy parts have been accelerated from rest by the usually small torque available. A capable designer will so proportion these factors as to reduce the effect of the inertia, and load curves are available recording considerable success in this direction. This does not, however, absolve the liquid slip-regulator in general from the imputation of sluggishness, in comparison with the statical resistor, the action of which must always be instantaneous.

Considerable importance having been attached to the curve in Fig. 4 by two speakers, I have repeated this test, employing a 5 per cent solution of common salt, at a temperature of 65° F., and a current density of 279 amperes per square foot at 50 periods per second. The resultant curve is given in Fig. A, the various readings being indicated by points on the diagram. There is very little room for doubt as to its passing through the origin, indicating that even the small contact potential mentioned by one speaker was absent. I had originally expected this, for it will be remembered that Kohlrausch employed what was practically the equivalent of this apparatus for measuring the resistance of electrolytes, as he found that, within certain limits, the E.M.F. of polarization is proportional to the quantity of electricity which has passed through the cell. The quantity being very small in the case of an alternating current, it would be expected that the E.M.F. of polarization would also be small compared with the steady value. The above test shows this to be the case.

North-Eastern Centre, at Newcastle, 27 February, 1922.

Mr. J. Schuil: Mr. Anderson has certainly succeeded in proving that the production of a good starter involves much study and design on sound principles. Referring to liquid starters and their smooth acceleration, I would mention the special resistance that I patented and brought out for Messrs. A. Reyrolle & Co., on the "wait on the first step until the motor starts" arrangement. This principle has very many advantages and is still occasionally asked for. Owing to the negative temperature effect of the carbon powder there is a current-growing characteristic which causes the motor to start at any reasonable load on the first contact, leaving the remaining studs for cutting out the resistance. In America, large starters are made with carbon plates under variable compression. The particulars of the test on resistance units mounted vertically are misleading; they may be true of a set of units in the open, but when in actual working condition with several side by side the top units get hotter than the bottom ones. The resistance now made by my firm consists of a unit which combines great storage capacity with quick heat-radiating effects. This is effected by clamping the resistance units between steel radiating plates. It makes an ideal resistance for ordinary starters, as there are no loose wires. I am very interested in the information given with regard to blow-outs. It has been my opinion for years that blow-outs on starters and controllers should not be of the series-wound but of the shunt-wound type, and I should be glad to have the author's opinion on this point. Messrs. Schuil produce a controller which includes a mono-break blow-out, where all the making and breaking is done on one set of contacts under a very heavy blow-out. Also, in a special, small starter the blow-out magnet is used as a hold-on magnet, with very satisfactory results.

With regard to liquid starters, there would appear to be little need of pushing the current density of the plates to anything like the figures mentioned by Mr. Wilson, as in most cases the size is practically settled by the heat-storing capacity of the liquid—so that allowing, say, 16 h.p. per gallon, the size of the starter is easily fixed by the cubic contents, and the plates may be as large as convenient. There seems to be some trouble in preventing the short-circuiting jump with some liquid starters. In both Mr. Anderson's and Mr. Wilson's papers many particulars of loads for special starters are given, but for ordinary design it is more useful to make a standard line of starters which will deal with ordinary requirements and give a reasonably cheap article. It is almost impossible to get a better price for a better article. The majority of orders are obtained on price only—especially when bought through trade, but, fortunately, good design tells in the end. In the standard designs it is usual now to calculate ratings by the B.E.A.M.A. rules, although for heavy duty special ratings are required.

Mr. G. G. Mallinson: A difficulty perhaps not generally recognized with starting switchgear lies in the difference in treatment by the user. Gear that gives every satisfaction with the skilled user gives nothing but trouble under the rough treatment which it receives in steel-works and shipyards. For the latter and for marine work, simplicity and robustness should be attained. Terminal and clamping screws should be large and easily accessible under the ironclad covers. Cast grid resistances have not given satisfaction, although if cast of the proper metal some have given good service. Often, however, resistances have been sent out with brittle metal, and these soon break, especially when used on a vibrating structure. A type of resistance in which the resistance element is embedded in some form of clay has often been used. This is not satisfactory, as the resistance varies with the amount of moisture in the air. If such a resistance is incorporated in apparatus controlling a creeping motion, the creep will vary considerably from day to day. A centre stop should always be provided for crane controllers, etc., and should be of a pattern that requires another hand to free as the controller handle is brought to the zero position. This avoids the violent switching-over from full speed in one direction to reverse. Most crane men try to do this when desiring a rapid stop and, naturally, electrical gear suffers. If properly designed and constructed automatic gear may be the best for practically all purposes. Control pushes or switches should, however, be double-pole. Voltage relay-operated gear has not given satisfaction in use. Starter makers have doubtless been handicapped by insufficient information from the user or from the motor manufacturer. On the other hand, however, in many cases insufficient notice has been taken of the sort of work to which the starter would be put. In this, closer co-operation than has obtained in the past is now being attained.

Mr. A. B. Johnstone (*communicated*): At the end of the paragraph dealing with the inertia of the moving parts of a slip-regulator, at the top of page 207 the statement is made that "Many loads, such as those in a rolling mill, cease abruptly, and the reverse action of the torque motor then becomes unimportant." Surely this view is incorrect. In the case of a large reversing mill with Ilgner set and Ward-Leonard control, as soon as the load goes off the d.c. motor at the end of a pass it is most important that as much flywheel energy as possible should be replenished in the short interval between passes. Obviously, therefore, unless the slip-regulator resistance is reduced quickly on a fall of load, the speeding-up of the flywheel set to an appreciable extent cannot possibly be accomplished before the next pass is commenced. This speeding-up action is especially important on the last two or three passes of a section-finishing mill. Such passes are long and in many cases the available flywheel energy is spent long before the end of the pass, although apart from the energy required for acceleration of the d.c. mill motor and rolls, the rolling load is comparatively light—a sustained light load in contrast to the heavier loads of short duration which are characteristic of the earlier passes. When we consider the energy required to speed up a 65-ton armature 10 ft. 6 in. in diameter, together with pinions and 36 in. diameter rolls, to 120 r.p.m. in 5 seconds or less, it will be realized that such energy constitutes a heavy peak load on the flywheel set and it is important, therefore, that the flywheels should be able to cope with this acceleration demand as far as possible. I find, from load curves taken during the rolling of several different sections, that the average time between passes from start to finish of rolling of one piece is about 5 seconds, and from this fact alone the need for extreme rapidity in reducing the slip-regulator's resistance the moment the d.c. load falls, is self-evident.

Mr. J. Anderson (*in reply*): With reference to Mr. Schuil's remarks, the use of a shunt or a series blow-out depends entirely on the conditions to be met. A circuit breaker which has to interrupt overloads of almost any value must have a series blow-out because the field increases with the severity of the short-circuit. A starter or controller has, however, to deal with anything from light load to full load, and a shunt blow-out is therefore the proper method as this gives a field of sufficient strength with only small load currents.

Mr. W. Wilson (*in reply*): The principal object of my paper on liquid rheostats has been to determine, to as full an extent as possible, the characteristics of the various components involved in the apparatus, and more especially the behaviour of the liquid itself under every condition likely to arise in practice. Although, as Mr. Schuil has indicated, in the usual type of liquid rheostat employed at the present time for merely ordinary purposes, there may be little need for using anything like the highest current densities reached in my tests, nevertheless there are many reasons why these figures are of importance. To begin with, it is advisable to know, with a view to contingencies of various descriptions, how an apparatus is likely to function for conditions considerably beyond its projected range, and especially what is the limit beyond which no further increase is justifiable, and what are the consequences if that limit be passed. Again, while

the "16 h.p. per gallon" rule may be considered to be satisfactory by those concerned with stationary loads of moderate amount, yet the designer of, say, a 3000-h.p. electric locomotive may not feel disposed to provide space and carrying capacity for the number of gallons demanded by this relation if the purpose can be served with less. A similar example was given by a speaker in the Birmingham discussion, who described a liquid rheostat for the regulation of motors for marine propulsion, employing a current density of as much as 3200 amperes per square inch (see page 213). Even for ordinary purposes it is by no means certain that the design will remain in its present state for an indefinite period, and further development may well call for higher densities. I am afraid that I do not quite follow Mr. Schuil's argument *re* standard lines, prices and design. The examples which I have described include a complete range of standard starters for ordinary working, and this seems to be what Mr. Schuil is advocating; but it is surely asking rather too much to require the control of all motors, engaged upon all species of loadings, to be effected by a standard apparatus, more especially as controllers for 10 000- or 30 000-h.p. motors hardly call for quantity production as yet.

I quite agree with what Mr. Johnstone has said regarding the advisability of losing no time in re-accelerating the flywheel of an Ilgner set. The statement in the paper that the reverse action of the torque motor was unimportant referred only to its effect upon the particular cycle under consideration. If the load ceases abruptly, the regulator will return to the off position in the same time whatever its setting, and the latter then becomes unimportant for the reverse action of the torque motor. Mr. Johnstone's data graphically enforce the necessity of reducing to the smallest possible amount sluggishness in the slip regulator.

DISCUSSION ON "SINGLE- AND THREE-PHASE A.C. COMMUTATOR MOTORS WITH SERIES AND SHUNT CHARACTERISTICS."*

SCOTTISH CENTRE, AT DUNDEE, 28 APRIL, 1922.

Mr. A. S. Hampton : Power companies have recently offered rebates on good power factors, and motors of this type afford the best means of getting a proper power factor with a.c. supply. This is one reason why such a paper is so much needed. Another reason is in regard to electric traction. The most recent motors on the Brighton Railway, which are also of this type, have given considerable satisfaction, showing the great progress made during the past 10 years, and it is becoming more and more evident that there is a future for a.c. electric traction. The behaviour of a.c. motors of recent manufacture has changed the opinion of many railway electrical engineers, and large a.c. motors of the commutator type seem to be more successful than d.c. motors for large electric locomotives. In this country railway traction has mostly taken the form of multiple-unit systems, but for main-line electrification it will be necessary to build some type of locomotive with motors larger than have hitherto been built for d.c. traction purposes ; and it would certainly appear as if the motor described by the author will fulfil a most useful purpose.

Mr. R. D. Archibald : The delay in new developments in this country compared with abroad has been due in the past to insufficient recognition of the abilities of the engineer, but fortunately that phase is passing away. In railway work it seems that we shall have both single-phase and direct-current systems developed in the country. At one time it was considered to be an advantage of the commutator motor that it could work on both a.c. and d.c. systems. The design and conditions of working of a.c. and d.c. motors are, however, very different. Can the author say how the question of interworking stands at the present time ?

Mr. D. H. Bishop : It seems to me that the fundamental difficulty with these motors lies in the fact that the main alternating flux acts upon the short-circuited coils in the armature. The method of combating this is to introduce a neutralizing flux by means of commutating poles. As this involves the exact balancing of two large quantities, it would seem to be inherently difficult to obtain and maintain sufficient accuracy to ensure successful running. Will not the motors be rather sensitive in the matters of brush setting, inequalities in air-gaps due to mechanical defects, or wear of the bearings ? Furthermore, it would appear that a small fault in the interpole winding or some other defect in the flux balance might cause the armature winding to burn out without increasing the main current sufficiently to open the circuit breakers.

Mr. W. S. Sawtell : The author states at the commencement of the paper that a.c. motors are required to-day to have the following characteristics : high power factor, large starting torque, and economical speed regulation. The last requirement is possibly of greatest importance to the engineer concerned with electric traction. Dundee has not as yet had to face that problem except for tramways, where direct current is used. With regard to high power factor, the consumer of alternating current in Dundee is offered a considerable reduction if he keeps his power factor above a certain figure. It would therefore be interesting to know in what way and to what extent the power factor of a commutator motor, designed to run with a high power factor and not necessarily for variable speeds, varies with the load ; whether such a motor can be designed to give the same power factor at all loads from, say, half to full load ; and, assuming this to be possible, to what extent, if any, this condition would affect the efficiency.

Mr. A. P. Robertson : The author has demonstrated that with voltage control the power varies directly as the speed, and that for certain purposes a smaller-sized motor would serve with voltage control than would be the case with a purely shunt motor. In this case, he shows that a 10-h.p. motor working at a low speed would develop 30 h.p. when working at 3 times the speed, and argues that in this case a 10-h.p. motor would be sufficient. In traction work, however, the speed is low when going up an incline but the torque required is greater, therefore the total horse-power required is great at low speeds, and the 10-h.p. motor would not be sufficient. One of the great drawbacks with a.c. motors is the difficulty of speed control. The tendency nowadays is to adopt a.c. distribution, and in Glasgow this policy is encouraged. The rates for a.c. supply are lower than those for direct current, for obvious reasons, and alternating current is certainly very much more convenient. In the average factory or engineering shop where electricity is used for power purposes, the majority of the machines are run at constant speeds, and a great many of them are run off countershafts—it does not always pay to install a separate motor for each machine—so that the question of speed variation is not so great as would appear at first sight. However, there are certain instances where speed variation is required, and the demands in most works are not excessive and may be anything from 5 to 50 h.p. for a variable-speed a.c. motor. Machines of this size are, of course, very much easier to make than those of, say, 500 or 600 h.p. In many works the attention given to motors is not of the best, and that is, I think, one of the principal reasons why we should try to dispense with commutators. One of

* Paper by Dr. S. P. Smith (see page 308).

the great advantages in a works using alternating current is the absence of commutators. As a consequence the motors are much easier to look after and, even where there are commutators, they are often ground up with a piece of sandstone or by some other temporary means. To keep the power factor of an induction motor high is of importance from the supply undertaking's point of view, and the power factor on the commutator motor can be improved more easily than on an induction motor without external means. It is then a question whether we should go ahead and try to improve the power factor on the induction motor by some means not yet evolved, or go further with the commutator motor. I think that both motors have their spheres of usefulness. For general industrial purposes, I think we should try to improve the wound-rotor and squirrel-cage types because these machines have no commutators, and are easier to look after with the type of labour often to be found in small works. The sphere of usefulness of the motors mentioned in the paper seems to be confined to traction. In traction work there is generally an experienced staff to keep the motors in good working order, and facilities are provided for grinding and repairing commutators and brush-gear. The question of upkeep therefore does not arise to the same extent as in industrial work, and if the prices of these motors are competitive—and I see no reason why they should not be—their characteristics entitle them to consideration in this respect. I should like to ask the author if he would recommend these motors or if he knows of any instances where they are employed in driving power-station auxiliaries, where the speed variation has sometimes wide limits.

Mr. W. B. Hird : It is quite clear that the author is not a whole-hearted advocate of the use of a.c. commutator motors. I think that while there is undoubtedly a field for such motors, this field lies entirely in their application to traction and to a few other very special cases. I do not believe that there is any large field of usefulness for this type of motor in ordinary industrial applications, and I think that the author would agree with me on this, although some parts of his paper might convey a somewhat different impression. The case in which commutator motors might at first sight appear to have advantages even in industrial applications is where speed variation and improvement of the power factor are wanted. The difficulties arising from the use of such motors quite offset the advantages they might have in these respects. In every case it would probably be found much easier and cheaper to put in a synchronous motor converter regulated so as to improve the power factor, and to install d.c. motors where speed regulation is required.

Dr. S. P. Smith (*in reply*) : In connection with Mr. Hampton's remarks, it may be in place to add that while the single-phase system for traction entails the use of a transformer on the locomotive or motor-coach, there is the resulting advantage of low-voltage motors and switchgear. On the other hand, with direct current it is scarcely feasible to exceed 1 500 volts per commutator, while some makers even prefer tolerating motors permanently in series to this voltage, though the high voltage to earth is not affected thereby.

In reply to Mr. Archibald, I think that interworking is seldom used nowadays. Combined single-phase and d.c. systems have been largely replaced by direct current—1 200 volts for inter-urban and 600 volts for urban service.

Mr. Bishop is misled in thinking that a large neutralizing field is necessary. A small interpole, e.g. a stator tooth, excited to give the correct phase and magnitude of flux density, is all that is needed, while exact counterbalancing is not essential. At speeds well above synchronism, the strength of the cross flux is low.

If Mr. Sawtell refers to Mr. Teago's paper,* he will see curves showing phase compensation over a wide load-range. Such results are not possible with all types of a.c. commutator motors, but, generally speaking, high power factors are possible (see also Mr. Creedy's remarks on page 314).

With reference to Mr. Robertson's remarks, the illustration of the 10- to 30-h.p. motor is chosen to meet various industrial requirements. The fact that the output at the low speed may not suffice for traction work does not affect the argument that with field weakening the motor is not fully utilized at high speeds. It would be wrong to assume that a.c. commutator motors are useful for traction work only—although it is unlikely that such motors will ever have such wide uses as the present standard types, there is an ever-increasing field of application for them to meet the needs of special cases.

Mr. Hird is right in stating that I am not a whole-hearted advocate of a.c. commutator motors. My position is rather that of a critic who wishes the characteristics of these machines to be better understood, so that they can be adopted in suitable cases. For this reason I should not agree with him that the synchronous motor converter would be preferable in most cases.

* See page 328.

DIRECTIONS FOR THE STUDY OF ELECTRICAL INSULATING PAPERS (UNTREATED) FOR PURPOSES OTHER THAN THE MANUFACTURE OF CABLES.*

(Report received from the British Electrical and Allied Industries Research Association.)

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* The term "untreated" denotes that the paper has not been varnished, impregnated or otherwise treated after despatch from the paper mill.

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Preface.

For several years this Association (and its predecessor, the E.R.C.) has been engaged in the study of papers to be employed for insulation (other than in the construction of electric cables) and in devising tests suitable for their examination.

During the course of the work the leading electrical manufacturers furnished particulars of the papers they were using for a variety of purposes, and their requirements in connection with such uses. Full particulars were obtained from the paper manufacturers also, of the methods employed in manufacture and the materials used. It soon became evident that there was no reliable system of nomenclature for these materials, the descriptions employed being fancy terms, or terms but loosely connected with particular qualities or materials. With the assistance of the parties interested a schedule of definitions has been prepared and is presented herewith, the use of which should go far to remove present ambiguities.

A large number of papers were then examined and tested in a variety of ways, and, as a result, a series of tests has been developed which have proved suitable for ascertaining the properties of chief importance which these materials should possess. These tests are described in the following pages, and are here presented in the confident belief that their use will lead to improvement in product. They are not devised as purchasing or acceptance tests, but furnish a basis for the development of such tests, which properly belongs to the activities of the British Engineering Standards Association. The data collected during the course of the work done will be useful to this end, and will be incorporated with other additional information in a report to follow.

I. DEFINITIONS.

In order to avoid the ambiguity associated with many of the terms in use in the paper trade, it is recommended that in defining papers for electrical purposes the following terms be adopted and that their use be confined to the materials described:—

Paper.

The term "Paper" denotes a matted or felted structure of fibrous material formed into a relatively thin sheet on a paper-making machine.

Pure Manilla Fibre Paper.

The term "Pure Manilla Fibre Paper" denotes paper made from Manilla Fibre only.

Note.—The best paper would be made from new fibre.

Manilla Paper.

The term "Manilla Paper" denotes a strong paper made from Sulphite Wood Pulp, but may contain some manilla and hemp fibre.

Note.—This paper is occasionally described as "Cartridge Paper."

Rope Paper.

The term "Rope Paper" denotes paper made from rope-ends.

Note I.—Rope paper is liable to contain iron particles.

Note II.—"Manilla" paper dyed red is sometimes designated "Red Rope Paper."

Chemical Wood-Pulp.

The term "Chemical Wood-Pulp" denotes wood-pulp prepared by a chemical process, as, for example, sulphate, sulphite and soda wood-pulp described below.

Sulphate Wood-Pulp (Kraft) Paper.

The terms "Sulphate Wood-Pulp Paper" and "Kraft Paper" denote paper made from wood-pulp only, by the sulphate process.

Sulphite Wood-Pulp Paper.

The term "Sulphite Wood-Pulp Paper" denotes paper made from wood-pulp only, by the sulphite process.

Soda Wood-Pulp Paper.

The term "Soda Wood-Pulp Paper" denotes paper made from wood-pulp only by the caustic soda process.

Note.—Paper made by this process is a soft and bulky paper.

Mechanical Wood-Pulp Paper (Core plate insulating paper).

The term "Mechanical Wood-Pulp Paper" denotes paper made from wood by the mechanical pulping process.

Jute Paper (Horn Fibre Paper).

The term "Jute Paper" denotes paper made from jute fibre without the use of chemicals.

Soda Rag-Pulp Paper.

The term "Soda Rag-Pulp Paper" denotes paper made from rags only, by the caustic soda process.

Lime Rag-Pulp Paper.

The term "Lime Rag-Pulp Paper" denotes paper made from rags only, by the lime and carbonate of soda process.

Rag Bond Paper.

The term "Rag Bond Paper" denotes paper made from linen and cotton rags only, and weighing more than 13 lb. per ream (480 sheets), post size (21 in. $\times$ 16½ in.).

Rag Bank Paper.

The term "Rag Bank Paper" denotes paper made from linen and cotton rags only, and weighing not more than 13 lb. per ream (480 sheets), post size (21 in. $\times$ 16½ in.).

Leather Paper (Fish Paper).

The term "Leather Paper" denotes paper made from cotton rags only, and afterwards chemically treated (generally with zinc chloride) to produce a homogeneous sheet of celluvert.

Tissue Paper.

The term "Tissue Paper" denotes paper of which the weight of 2 000 square feet does not exceed about 9 lb.

Best Rag Tissue (Condenser or Electrical Tissue) Paper.

The terms "Best Rag Tissue Paper," "Condenser Tissue Paper" and "Electrical Tissue Paper" denote tissue paper made from rags only.

Note.—The term "Electrical Tissue Paper" is generally used for the heavier grades.

Cotton Tissue Paper.

The term "Cotton Tissue Paper" denotes tissue paper made from cotton rags only.

Silversmiths' Tissue Paper.

The term "Silversmiths' Tissue Paper" denotes tissue paper made from rags only, grass bleached, and free from chemicals and loading material.

Sulphite Tissue Paper.

The term "Sulphite Tissue Paper" denotes tissue paper made from wood-pulp by the sulphite process, but may contain some rag pulp.

Sulphite Imitation Japanese Tissue Paper.

The term "Sulphite Imitation Japanese Tissue Paper" denotes soft porous tissue paper made from wood-pulp by the sulphite process.

Japanese Gampi Tissue Paper.

The term "Japanese Gampi Tissue Paper" denotes tissue paper hand-made from the *Wickstroemia puciflora.*

Japanese Kodzu Tissue Paper.

The term "Japanese Kodzu Tissue Paper" denotes tissue paper made from the *Broussometia papyrifera* (Paper mulberry).

Note.—Two qualities of this paper are in general use.

Japanese Tosa Dental Tissue Paper.

The term "Japanese Tosa Dental Tissue Paper" denotes soft porous tissue paper made from the *Broussometia papyrifera* (Paper mulberry) in the Tosa district.

Note.—This paper is superior to the Mino Dental Tissue.

Japanese Mino Dental Tissue Paper.

The term "Japanese Mino Dental Tissue Paper" denotes soft porous tissue paper made from the *Broussometia papyrifera* (Paper mulberry) in the Mino district.

Note.—This paper is inferior to the Tosa Dental Tissue.

II. PROCESSES OF TREATMENT DURING MANUFACTURE.

During manufacture the papers defined above are subjected to one or more of the processes described below :—

Bleaching.

Bleaching is carried out on the pulp before it is made into paper. The usual agent is chloride of lime.

Loading.

Loading consists of filling up the interstices between the fibres to impart appearance and weight. The usual substances employed are Kaolin (china clay), calcium sulphate and "brokes."

Note.—"Brokes" is the name given to paper which is spoiled during the course of manufacture.

Colouring.

The term "Colouring" denotes the production of *coloured* pulp, or a pure (or toned) *white* pulp, after it has been bleached. The colour is produced by the addition of either mineral, or other pigments or aniline dyes, to the pulp. Whiteness is produced by the addition of ultramarine or cochineal to the pulp for the best papers, and aniline blues for the cheaper papers.

Staining.

The term "Staining" denotes applying a coating of dye to the surface of the paper.

Sizing.

The term "Sizing" denotes a process employed to impart strength to the paper.

Three principal sizing treatments are employed as follows :—

(*a*) *Resin* (*or Engine*) *Sizing* (*Hard Sizing*).

Resin Sizing is carried out by the addition of resin to the pulp in the form of sodium resinate, and alum in the form of aluminium sulphate.

(*b*) *Viscose Sizing.*

Viscose Sizing is carried out by the addition of viscose to the pulp with or without resin.

Note.—Viscose is made from cellulose in the form of bleached cotton or wood pulp by treatment with sodium hydrate and then with carbon disulphide, which converts the cellulose into a gelatinous transparent mass soluble in water. The crude solution thus obtained is refined by treatment either with saturated brine or with alcohol.

(*c*) *Gelatine* (*or Animal or Tub*) *Sizing* (*Soft Sizing*).

Gelatine Sizing is carried out by coating the finished paper with gelatine, glue or casein.

Parchmentising (*Hydro-Cellulose*).

The term "Parchmentising" denotes an acid (or alkali) treatment so as to render the paper grease-proof.

Hydration (*Hydra-Cellulose*).

The term "Hydration" denotes the incorporation of water with the fibres producing a kind of gelatinous film. This result is obtained by beating the pulp in a suitable manner for a sufficiently long time. This process is used in the production of grease-proof and similar papers.

Glazing.

Four methods of glazing are employed, as follows:—

(*a*) *Machine Glazing* (*M.G.*).

Machine Glazing is carried out by passing the paper over a hot cylinder during the course of manufacture. One side of the paper only is machine glazed.

(*b*) *Friction Glazing* (*F.G.*).

Friction Glazing is carried out by passing the paper between warm cylinders which are treated with either beeswax or paraffin wax.

(*c*) *Super-Calendering* (*S.C.*).

Super-Calendering is carried out by passing the paper through a machine consisting of a stack of cylinders

(4–12) of polished steel and compressed paper or cotton, arranged alternately, the former being heated. The paper is usually damped before passing through the super-calender.

(*d*) *Plate Glazing* (*P.G.*).

Plate Glazing is carried out by placing the paper between plates of polished copper and subjecting them to pressure.

Note.—Plate glazing is chiefly confined to hand-made papers, superfine litho papers and the like.

Machine Finish (*M.F.*).

When paper is not glazed, a slightly smooth surface is imparted to it during its travel through the paper-making machine. This is known as machine or mill finish.

III. TESTS.

The tests given below are recommended for the study of Electrical Insulating Papers.

The Schedule at the end of the Specification indicates which tests are most appropriate for papers intended for the various specific applications shown.

Clause No.	Schedule of Tests
1	Conditioning of Specimens for Test.
2	Determination of Thickness.
3	Determination of Density.
4	Tensile Strength and Extension.
5	Ageing (Bursting Test).
6	Tearing Strength.
7	Porosity.
8	Chemical Tests.
	(*a*) Moisture loss on drying at 100° C.
	(*b*) Acidity and Alkalinity.
	(*c*) Mineral Ash.
	(*d*) Sizing.
9	Chemical Tests for Metallic Particles.
10	Flash Test for Conducting Particles.
11	Crinkling under Tension.
12	Microscopical Examination.

1. Conditioning of Specimens for Tests.

Before the tests specified in Clauses **4**, **6**, **7** and **8** (*a*) are carried out, single sheets of paper shall be conditioned in a controlled atmosphere for not less than **18** hours. The controlled atmosphere shall have a relative humidity of **75** per cent and a temperature of 70° F. (21·1° C.).

The specified relative humidity shall be obtained by the use of a solution of sulphuric acid in water, specific gravity 1·220.

The paper shall be tested as soon as possible after removal from the controlled atmosphere, and in any case before **3** minutes have elapsed.

Note.—The method of conditioning given above cannot be applied to paper in rolls, which must be cut up before conditioning.

2. Determination of Thickness.

The thickness of the paper shall be measured by means of a micrometer fitted with a rachet head. The measuring faces shall be not less than $\frac{1}{4}$ inch and not more than $\frac{1}{2}$ inch diameter, and one face shall be free to swivel.

The average thickness of the paper shall be ascertained as follows :—

In the case of rolls, after the three outer layers have been removed a test-piece one foot long and the full width of the roll shall be taken. Ten measurements of thickness equally spaced diagonally across the test-piece shall be made.

In the case of sheets, ten measurements equally spaced diagonally across the sheet shall be made.

The maximum, minimum and mean values of thickness shall be stated.

3. Determination of Density.

The density expressed in terms of weight in grammes per cubic cm of volume shall be ascertained by weighing and measuring, in an artificially dried atmosphere, samples, not more than 8 inches (20 cm) square, immediately after they have been heated at a temperature of 212° F. (100° C.) for three hours.

4. Tensile Strength and Extension.

The paper shall be conditioned in accordance with Clause **1** before the tests for tensile strength and extension are carried out.

For the purpose of the test for tensile strength and extension at least **12** samples for test shall be taken. Six of these shall be cut in the direction of the length of the paper and six across the width of the paper.

The dimensions of each test-piece shall be $\frac{5}{8}$ inch wide by **10** inches long so as to give **6** inches clear between the testing jaws.

The load shall be applied gradually, and the test shall be carried out in such a manner that the tensile strength in lb. per square inch (kg per sq. cm) sectional area, and the percentage extension on the original length under load, can be determined.

In computing the tensile strength of the paper the mean thickness obtained in accordance with Clause **2** shall be taken.

The maximum, minimum and mean values of tensile strength and of percentage extension shall be stated.

For the method of determining the direction of "length" and "width" of paper when supplied in sheets, see Appendix.

5. Ageing (Bursting Test).

The tendency of the paper to deteriorate with age shall be proved by a comparison of the bursting strength of the paper before and after it has been heated in a drying oven at a temperature of 230° F. (110° C.) for **24** hours. The paper shall be conditioned in accordance with Clause **1** before the bursting test is carried out in each case. The bursting strength of the paper shall be determined in accordance with the following method :—

The paper shall be gripped on to a ring leaving a free circular membrane which shall be subjected to fluid pressure until it is broken. The value of the pressure required to break the paper, shown on an indicator attached to the apparatus, shall be expressed in lb. per square inch (kg per sq. cm).

This value is defined as the bursting strength of the paper.

The bursting strength of the paper shall be measured at ten positions equally spaced diagonally across a test-piece one foot long and the full width of the roll, when the paper is submitted in a roll, and at ten positions equally spaced diagonally across a sheet, when the paper is submitted in sheets.

The maximum, minimum and mean values of the bursting strength shall be stated.

The direction in which the paper commences to break with respect to the length of the paper shall be noted.

For the method of determining the direction of "length" and "width" of paper when supplied in sheets, see Appendix.

A suitable apparatus for carrying out the test is shown in Fig. 1.*

6. Tearing Strength.

The paper shall be conditioned in accordance with Clause 1 before the tearing strength test is carried out.

The resistance to tearing shall be proved by the load required to tear the paper commencing from a hole 3/32 inch diameter punched out of the paper. The position of the hole and application of the load shall be as shown in Fig. 2.

The size of each separate specimen tested shall be 6 inches square.

(*a*) Three tests shall be made with the tear in the direction of the length of the paper. This shall be called the "Length Tear Test."

(*b*) Three tests shall be made with the tear across the width of the paper. This shall be called the "Width Tear Test."

For the method of determining the direction of "length" and "width" of paper when supplied in sheets, see Appendix.

The method of carrying out the tearing test shall be as follows:—

Prepare the paper specimen as shown in Fig. 2.

Swing the inverted "L" piece to the right.

Place the paper in position, the punched hole being at the angle of the "L" piece as indicated.

Screw the "L" piece down. Bend over the cut piece "A" ($\frac{1}{2}$ in.), shown dotted, and attach grip device—needle or clip—and secure to lower portion of balance.

Rotate the winding gear with steady movement at a rate of approximately 12 inches per minute until the 6-inch length is torn through. (A motor drive is recommended.)

Watch the balance and average the slightly varying values of the pull observed.

The maximum, minimum and mean values of the "length" and "width" tearing strengths respectively shall be stated.

7. Porosity.

The paper shall be conditioned in accordance with Clause 1 before the porosity test is carried out.

* Fig. 1 is not reproduced here

The porosity of the paper shall be determined by means of the following apparatus, which shall be assembled as shown in Fig. 3.

Glass burette graduated 0 to 100 cc (length of 100 cc graduations approximately 22 inches) and fitted with a stopcock at top.

Two metal clamping discs having 1 inch recess in one and 1 inch hole in the other. The inner side of each disc shall be faced with sheet rubber 1/32 inch thick.

Aspirator bottle approximately 300 cc and $2\frac{3}{4}$ inches diameter fitted with a rubber tube connection at bottom.

Three feet of rubber tubing, internal diameter 3/16 inch and external diameter 7/16 inch.

Ring stand approximately 4 feet high.

The test shall be carried out as follows:—

Open the stopcock of the burette, and place the aspirator bottle in the upper support. The bottle shall contain sufficient water, and the upper support shall be so adjusted that when the surface of the water in the burette coincides with the zero mark the depth of the water in the bottle is about one inch.

A strip of paper $2\frac{1}{4}$ inches wide shall be cut from the roll or sheet. The length of the strip shall be equal to the full width of the roll or sheet. The strip of paper shall be clamped between the rubber-faced metal discs, the stopcock closed and the bottle lowered until the surface of the water is 24 inches below the zero mark of the burette. The stopcock shall then be opened for 15 seconds, which shall be measured by means of a stop-watch or similar instrument. Immediately after the stopcock has been closed the bottle shall be raised until the surface of the water in the bottle is in the same horizontal plane as that in the burette. The water level in the burette shall then be noted. This reading, which shows the number of cubic cm of air drawn into the burette through the paper, shall be taken as the porosity number of the paper.

The porosity of the paper shall be measured at 10 points, 5 inches apart, located across the width of the roll or sheet.

The maximum, minimum and mean values of the porosity number shall be stated.

When the width of the roll or sheet is insufficient to enable 10 tests to be made on one strip, two or more strips shall be tested.

For the method of determining the direction of "length" and "width" of paper when supplied in sheets, see Appendix.

8. Chemical Tests.

(*a*) *Moisture Loss on Drying at* 212° F. (100° C.).

The paper shall be conditioned in accordance with Clause 1 before the test for moisture loss is carried out.

Approximately 25 grammes of the sample shall be weighed after conditioning, dried at a temperature of 212° F. (100° C.) for 3 hours and then re-weighed in an artificially dried atmosphere. The moisture loss shall be computed as a percentage of the weight of the sample after conditioning and before drying.

(*b*) *Test for Acidity and Alkalinity.*

The test for acidity and alkalinity shall be carried out as follows:—

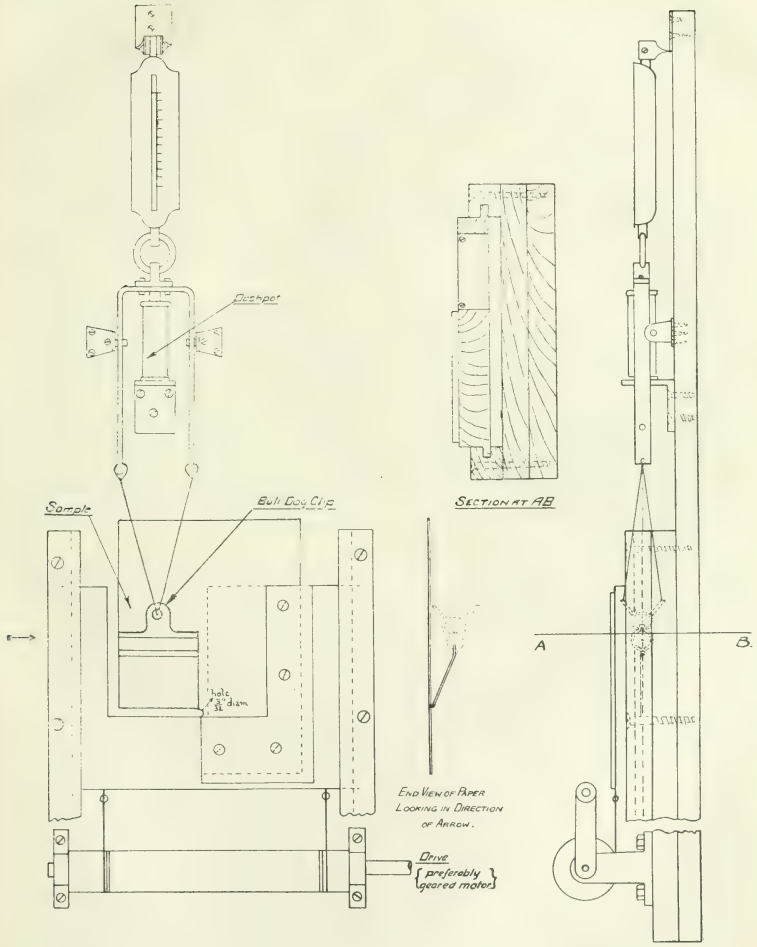

FIG. 2.—Apparatus for measuring the tearing strength of paper.

Cut up 30 to 40 grammes of the dried sample into pieces, weigh off duplicate lots of 10 grammes each, introduce each into a one-quarter litre flask, and add to each 200 cc of distilled water. Boil for 20 minutes, decant the solution through a perforated disc, wash each lot of paper twice with 75 cc of warm water. Titrate filtrates, using methyl orange indicator.

If the indicator shows the solution to be alkaline, titrate (neutralize) it with a standard centinormal solution of sulphuric acid:

$$\frac{N}{100}H_2SO_4$$

If the indicator shows the solution to be acid, titrate (neutralize) it with a standard centinormal solution of sodium hydrate:

$$\frac{N}{100}NaOH$$

or potassium hydrate:

$$\frac{N}{100}KOH$$

In each case the number of cubic centimetres of the reagent required to neutralize the paper shall be stated.

(c) Mineral Ash Test.

About 25 grammes of the dry sample obtained from the determination of moisture test shall be very completely ignited with all precautions against loss. The residue of incombustible mineral matter (ash) shall be weighed, and the amount computed as a percentage of the weight of the dried sample.

(d) Sizing Tests.

(i) *Resinous Material.*

The total resins in the size shall be determined as follows:—

Five grammes of the paper shall be cut into strips about $\frac{1}{2}$ inch wide and folded into numerous small cross-wise folds. These shall be placed in the siphon cups and acidulated alcohol (900 cc of 95 per cent alcohol, 95 cc distilled water, and 5 cc glacial acetic acid) shall be poured into the cup until it starts to siphon over. When this has entirely siphoned over into the shell-shaped extraction flasks, approximately 200 cc more of the acidulated alcohol shall be added to the siphon cup which is then connected to the condenser. The flask shall be set into a steam bath and the extraction shall proceed for about 2 hours, or until the cup has filled and siphoned over about ten times.

The extract shall be poured into a weighed glass dish and the flask washed out with a small portion of the acidulated alcohol, which is added to the original extract. The alcohol shall then be evaporated and just before the extracted total resins in the glass evaporating dish go to dryness, they shall be cooled, taken up with 25 cc of ether, and transferred to a 250 cc separatory funnel containing 100 cc of distilled water and 25 cc of a saturated solution of sodium chloride, the latter being present to prevent the formation of an emulsion. The funnel shall be shaken thoroughly and the contents allowed to separate. The water shall be drawn off into a second separatory funnel, and washed again with 25 cc of ether.

The two ether extracts shall be combined and washed two or three times with 100 cc of distilled water to remove all the salt and foreign matter other than ether-soluble resins. Should glue, which is extracted from the paper by the alcohol, interfere by emulsifying with the ether it may be removed readily by adding a strong solution of sodium chloride to the combined ether extracts, shaking thoroughly and draining it off, repeating, if necessary, before washing with distilled water. The washed extract shall be transferred to a weighed glass dish, evaporated to dryness slowly, dried in an oven at 95° C. (203° F.) to 100° C. (212° F.) for one half-hour, cooled and weighed. The increase in weight of the dish divided by 5 and multiplied by 100 will give the percentage of total resins.

(ii) *Nitrogenous Material (Glue and Casein).*

The total nitrogenous material in the size shall be determined by the Kjeldahl-Gunning method described in *Atack's Chemists' Year-book*, 1921 edition, page 130, as follows:—

"About 1 gm of the paper is cautiously treated in a long-necked resistance flask with about 20 cc of conc. sulphuric acid (excessive frothing must be avoided). The heating is continued until the frothing subsides and then the flask is allowed to cool. (The nitrogen has been converted into ammonium sulphate.) Ten gm of potassium sulphate and a crystal of copper sulphate are added and the flask again heated until the contents are of a pale-green colour. Cool and dilute with 500 cc of distilled water.

One hundred cc of 30 per cent caustic soda are carefully poured down the side of the flask, avoiding mixing with the acid. The flask is connected with the acid absorption apparatus, the contents of the flask shaken up and the liberated ammonia distilled into excess N/10 acid. This is back titrated with N/10 caustic soda and the ammonia titration calculated to nitrogen.

A blank test must be carried out."

If no casein be present the percentage of nitrogen obtained multiplied by 5·6 will give the percentage of glue in the sample of paper.

Note.—This test is of no value for the determination of the percentage of glue when glue and casein are present, since both contain nitrogen.

9. Chemical Tests for Metallic Particles.*

The following tests shall be carried out on three samples of paper, each not less than one foot square,

* The hydrochloric acid in test (*a*) has a tendency to act upon the iron oxides present, thus producing considerable discoloration of the paper. Test (*a*) does not readily disclose the presence of copper and brass particles.

Test (*b*) detects iron, copper and brass particles, but it is not sufficiently penetrating, especially when testing dark paper, and metallic particles well inside the sample may not be disclosed. Also, after a short time, the discoloration extends throughout the sample, thus causing difficulty in detecting the metallic particles.

Test (*c*) does not indicate the metallic oxides.

from every roll, or on separate sheets from each ream :—

(*a*) The paper shall be saturated with a dilute solution of hydrochloric acid, specific gravity approximately 1·1, and then immersed in a potassium ferrocyanide solution to precipitate the iron present. Each iron particle will produce a blue spot on the paper.

The number of deeply stained particles per square foot of paper shall be stated.

(*b*) A 1 per cent. solution of silver nitrate shall be applied to the surface of the paper. Each metallic particle will produce a black spot on the paper.

The number of black spots per square foot of the paper shall be stated.

(*c*) The sample of paper shall be dipped into a 1 per cent solution (by volume) of acetic acid, and then allowed to air-dry for 1 hour while lying flat on a cloth.

When dry, the sample shall be dipped again in a solution containing 0·1 cub. cm acetic acid and 0·1 gramme of potassium ferricyanide in 100 cub. cm distilled water.

Each metallic iron particle will produce a blue spot on the paper, and each copper, brass or gun-metal particle a red spot.

The number of blue and red spots, respectively, per square foot of the paper shall be stated.

Note.—The potassium ferricyanide solution should be tested before use with some precipitated ferric hydroxide dissolved in strong nitric acid, and diluted with water. The potassium ferricyanide solution should give no blue precipitate or coloration.

10. Flash Test for Conducting Particles.

It is not necessary to condition the paper prior to carrying out this test, provided the paper has been stored so as to attain the condition of ordinary room humidity.

The paper shall be drawn at a speed of 2 feet per minute between a metallic plate and a system of overlapping rollers, arranged as shown in Fig. 4.

The rollers shall be of brass, 3 inches long and $\frac{7}{8}$ inch diameter. The edges of the rollers shall be rounded to a radius of 1/32 inch. Each roller shall exert a pressure of approximately 10 oz. on the paper under test.

The paper shall be subjected to an alternating potential difference of 50 volts (R.M.S.) per mil thickness of the paper. The frequency of the potential difference shall be 50 $\sim$ per second. A resistance shall be inserted in the testing circuit to limit the current so that the electrodes are not damaged when a puncture occurs. An electric lamp or other suitable indicator shall be used to demonstrate failure of the insulation.

On a failure occurring the defective spot shall be marked and the paper then drawn back and passed through a second time. The ability of the part originally defective to pass test on second application shall be noted.

Not less than 5 square feet of paper shall be tested. The number of punctures per square foot shall be stated.

11. Crinkling under Tension.

Note.—It is sometimes necessary to investigate the tendency of paper to crinkle, especially after "varnish treatment" when wound under tension between rollers. The crinkling is associated with the elongation and the porosity of the paper. Further information is required before a satisfactory clause can be drafted.

12. Microscopical Examination.

A microscopical examination of the paper shall be carried out for the purpose of identifying the fibrous materials from which it had been made. The approximate percentage of the constituent fibres shall be stated.

The following method of preparing the samples for microscopical examination and the means of identification of the fibres are recommended by the U.S. Bureau of Standards *:—

"Ten specimens, each about the size of a sixpence shall be cut from separate sheets, when the paper is submitted in sheets, or from different positions in the length of the roll, when the paper is submitted in a roll. The 10 specimens shall be torn into small pieces and placed in a 50 cc beaker to which approximately 20 cc of a 0·5 per cent solution of caustic soda is added.

The beaker is placed on a hot plate or stove and brought to a boil, but the boiling is not continued for more than a minute or two. The liquor is drained off and the pieces of paper are washed several times with tap water, care being taken that none is lost. They are then washed with approximately 20 cc of 0·5 per cent solution of hydrochloric acid, and then washed twice more with tap water. A portion of the small pieces is rolled between the fingers into a pill about the size of a small pea and transferred to a test tube, which is half filled with water. The test tube is shaken until the paper is disintegrated into fibres. By means of a glass tube of about 5 mm internal diameter a representative amount of the fibres is transferred to a glass slide and the water removed by placing several thicknesses of hard filter paper on either side of the slide. After the excess water has been thus removed, a strip of filter paper is placed on the fibres to absorb any traces, leaving the fibres dry, but not so dry that there will be difficulty in separating them. Two or three drops of the zinc-chloride-iodine stain described below are placed on the fibres, which are teased out with steel needles until the fibres are reasonably uniformly distributed and free from knots of fibres.

Composition and Preparation of Zinc-Chloride-Iodine Stain.†

25 cc saturated zinc chloride solution at 70° F. (21·1° C.).
5·25 gm potassium iodide.
0·25 gm iodine.
12·5 gm distilled water.

* Circular No. 107, "The Testing of Paper."

† This formula is tentative. Its value is subject to a number of factors that are now being studied by the Paper Section, Bureau of Standards, U.S.A.

The last three ingredients are mixed together and the zinc chloride added. The insoluble matter is allowed to settle at least overnight and the supernatant liquid decanted off. The stain must be kept in the dark or in a bottle opaque to light. It may be made

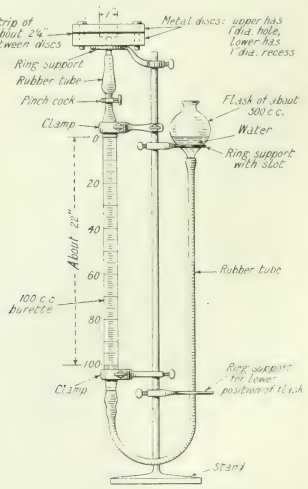

Fig. 3. -Apparatus for measuring the porosity of paper.

up in larger quantities provided it is kept from the light and air.

After the fibres are properly teased out with the needles, another but thinner glass slide is placed on top of the first slide, and the excess stain is squeezed out and absorbed by blotting-paper. The slide is now ready for the microscope. (A magnification of about 50 diameters is usually found convenient.) Care must be observed to keep the slide away from the light before using it for the estimation, and in any case the estimation should be made at least within one hour from the time the slide was made up. Under the microscope, using the zinc-chloride-iodine stain, the fibres appear coloured as follows :—

Cotton and linen rags	Wine red
Cooked and bleached manilla	
Cooked and bleached wood-pulp	Blue to blue violet
Cooked and bleached straw and esparto	
Mechanical or ground wood-pulp	Yellow to lemon yellow
Jute, uncooked, and manilla	
Highly lignified fibres	

In making the estimation both the distinctive shape and markings of the fibres, as well as the colours as developed by the zinc-chloride-iodine stain, are of importance. Extreme care must be observed to have

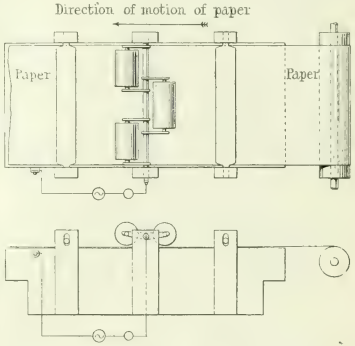

Fig. 4.—Apparatus for flash test for conducting particles.

all beakers, test tubes, needles, and even fingers free from any fibrous material before beginning the preparation of a sample or slide."

Reproductions of micro-photographs showing the fibres in papers containing the following materials are given in Fig. 5 (*a*) to (*f*) for comparison :—

(*a*) Rag (cotton and linen).
(*b*) Manilla.
(*c*) Jute.
(*d*) Chemical Wood-pulp.
(*e*) Mechanical Wood-pulp.
(*f*) " Paper mulberry " (*Broussometia papyrifera*).

IV. SCHEDULE OF USES, TESTS AND PAPERS.

A cross indicates that the test as described in the Specification shall be carried out.

Uses	Tests													Description of Suitable Papers in General Use
	Determination of Thickness	Determination of Density	Tensile Strength and Extension	Ageing	Tearing Strength	Porosity	Chemical Tests: Moisture Loss on Drying	Acidity and Alkalinity	Mineral Ash	Sizing	Chemical Test for Metallic Particles	Flash Test for Conducting Particles	Microscopical Examination	
1. Papers Used as Insulation: Manufacture of tubes and sheets	X	X	X	X	X	X	X	X	X	X	X	X	X	Chemical Wood-pulp
Between layers of windings and similar purposes	X	X	X	X	X	X	X	X	X	X	X	X	X	Chemical Wood-pulp, Manilla, Jute, Rag Bond, Best Rag Tissue
Insulating wrappings ..	X	X	X	X	X	X	X	X	X	X	X	X	X	Chemical Wood-pulp, Manilla, Jute
Between punchings	X	—	—	—	X	—	—	—	—	—		—	—	Chemical Wood-pulp, Mechanical Wood-pulp
Condensers	X	X	X	X	X	X	X	X	X	X	X	X	X	Condenser or Electrical Tissue
2. Papers Used as Insulation and as Mechanical Protection: Slot insulation	X	X	X	X	X	X	X	X	X	X	X	X	X	Manilla (Red), Red Rope, Jute, Leather
Wrapping core bolts.. ..	X	—	X	X	X	X	X	—	—	—	X	X	—	Manilla (Red), Red Rope, Jute, Leather
Bobbin flanges and other parts where high insulation is not required	X	—	X	X	X	X	X	X	—	—	X	X	—	Manilla (Red), Red Rope, Jute, Leather
3. Paper Used as a Mechanical Support in Building up Insulating Materials: Backing for mica foilum, mica tape or micanite	X	—	X	X	X	—	—	X	—	—	—	—	X	Chemical Wood-pulp, Manilla, Japanese Kodzu Tissue, Japanese Dental Tissue, Sulphite Imitation Japanese Tissue
Covering for micanite ..	X	—			—	—		X	—	—	—	—	—	Sulphite Tissue

FIG. 5.—(*a*) Rag (Cotton and Linen).

FIG. 5.—(*b*) Manilla and chemical wood-pulp.

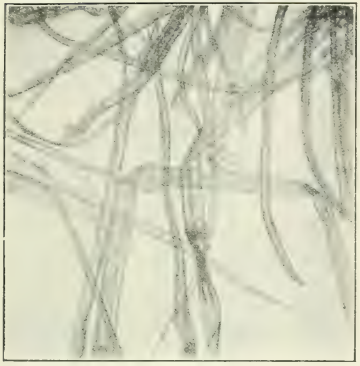

FIG. 5.—(*c*) Jute and chemical wood-pulp.

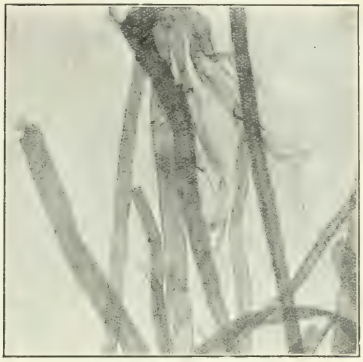

FIG. 5.—(*d*) Chemical wood-pulp.

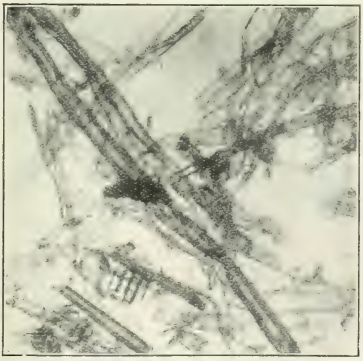

FIG. 5.—(*e*) Mechanical wood-pulp.

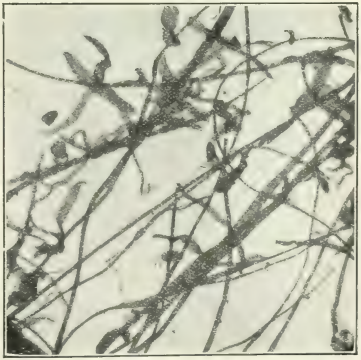

FIG. 5.—(*f*) "Paper mulberry."

APPENDIX.

Method for Determining the Direction of "Length" and "Width" of Paper, for Use in Carrying out the Tests Specified in Clauses 4, 5, 6 and 7.

(See Fig. 6.)

The direction of the "length" and "width" of the paper may be ascertained by the "Direction Test" as follows:—

Let a strip about $\frac{1}{2}$ in. width and 5 in. length be cut from one edge of the sheet under test and a similar strip cut from the adjacent edge at right angles to the first strip. On attempting to hold these strips vertically in the air between the finger and thumb they will fall over as shown in Fig. 6.

The upper strip "A" has its fibres parallel to the length of the strip and serves to indicate the edge from which it was cut as the "length" of the paper. The other strip "B" indicates the "width" of the paper.

Should the "length" strip, by chance, be the uppermost one when held between the fingers, the strips will be touching each other.

If the strips be waved over in the opposite direction to right or left, this will separate the strips and bring the "length" one uppermost.

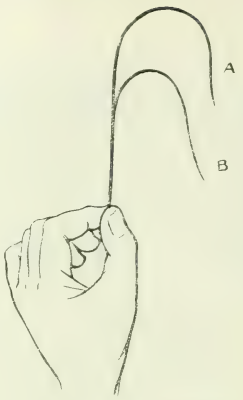

Fig. 6.—Test for "length" and "width."

PROCEEDINGS OF THE INSTITUTION.

108th Meeting of the Wireless Section, 1 February, 1922.

(Held in the Institution Lecture Theatre.)

Professor G. W. O. Howe, D.Sc., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting of the Wireless Section held on the 4th January, 1922, were taken as read, and were confirmed and signed.

A paper entitled "The Determination of the Decrement of a Distant Station by Means of a Coil Aerial," by Major J. Erskine-Murray, D.Sc., Member, and Mr. B. Williams, B.Sc. (see page 347), and one entitled "Directional Transmission of Electromagnetic Waves for Navigational Purposes," by Major J. Erskine-Murray, D.Sc., Member, and Dr. J. Robinson (see page 352), were read and discussed and the meeting terminated at 7.50 p.m.

677th Ordinary Meeting, 2 February, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The minutes of the Joint Meeting with the Institution of Heating and Ventilating Engineers held on the 19th January, 1922, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

A paper by Messrs. L. Romero and J. B. Palmer, Associate Members, entitled "The Interconnection of Alternating-current Power Stations" (see page 287), was read and discussed and the meeting terminated at 7.30 p.m.

678TH ORDINARY MEETING, 16 FEBRUARY, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 2nd February, 1922, were taken as read, and were confirmed and signed.

Messrs. A. T. Dover and H. C. Healey were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

Members.

Bremner, Ashton.
Chapman, Arthur Edgar.
Comport, George Henry.
Kramer, John Baptist.
McIlroy, Robert.
Rand, Percy Nathaniel.
Thow, James Hay.

Associate Members.

Bates, Albert.
Cunliffe, Robert Clayton.
David, Professor William Thomas, M.A., D.Sc.
Gould, Robert Howe.
Jack, Thomas.
Jones, Thomas Vachell.
Lea, Norman, B.Sc.
Lewis, Tom.
May, Ralph Whistler
Moody, Sidney.
Pickett, Francis Norman.
Riddell, Stuart Frederick J.
Warner, Arthur.
Waters, Ernest William.

Graduates.

Atkinson, Colin Eric.
Bailey, Walter Horace.
Burnham, Walter Witt.
Dalton, George Allan.
George, John Caslett.
Godley, Thomas.
Goldup, Thomas Edward.
Keating, Albert Ernest.
Panthaki, Jehangir Sorabji.
Webb, Alfred John.
Williams, Vernon Eustace.
Wright, Cyril William.
Wright, Robert.
Yates, John Farrell, B.Sc. (Eng.).

Students.

Adams, George Herbert.
Advani, Lilaram Hiranand.
Allen, John William.
Andrews, Arthur Edward D.
Angier, John Ralph T.
Austin, Cyril.
Barry, Louis.
Bartho, Francis Trenam.
Beach, William Robert.
Binns, Joshua William.
Birdsall, Charles.
Birmingham, William.
Bridgman, William Edward.
Brooks, Clement Arthur.
Browell, Frederick William.
Brown, Ronald Stewart.
Brydon, Thomas William.
Buckingham, George Somerset.
Burbridge, Philip George H.
Cater, Clinton.
Clark, George Reginald.
Clarke, George Bellard.
Clarricoats, John.
Cook, Adolf.
Cross, Leonard Jack.
Curtis, Matthew John W. E.
Davies, David Harold.
Derbyshire, Alfred Edgar.
Dracup, Frank Ackernley.
Duthie, George Ferguson.
Dyson, Albert.
Edmondson, George Allan.
Egginton, John Leslie.
Emerson, Richard Andrews.
Esmond, Leslie Purcell.
Falkus, Arthur Everest.
Fraser, Sidney Harold.
Gabbott, Thomas.
Gates, Benjamin George.
Gilson, Eric Friend.
Gorton, Eric John.
Govier, John Seymour.
Gow, George Alexander.
Grant, Frederick George.

Students—continued.

Gray, Richard Edmond.
Grech, Vincent Owen.
Guest, Harry.
Gunn, Jack Henry.
Hale, Robert Mathew.
Hammond, Joseph Winfield.
Harries, Donald George.
Harris, Frederick Henry.
Harrison, George Ernest.
Helden, Albert Edward.
Hinton, Sydney.
Hugh-Jones, Trevor Waite.
Hutchinson, John Thomas.
Johnson, Arthur.
Johnstone, Arthur Spencer.
Kaufmann, Max.
Kaufmann, Maximilian Joseph.
Kehoe, Hugh.
King, Arthur John.
Kirby, Colin Cameron.
Knight, Rupert Pontifex.
Lancaster, George Harold.
Lineker, Alexander William.
Lingard, Harold.
Lywood, Wallace Drake M.
McConway, Hugh.
McLean, Matthew Wilson.
Malam, William Charles.
Malik, Shah Zaman.
Marr, John.
Mukerji, Prosad Kumer.
Murray, Kenneth George.
Nelson, Jack.
Omar, Sidiqi Mohammed.
Ormerod, William Pass.
Otty, William.
Parry, Hugh Clive.
Parsons, David Cyril A.
Phillips, Edmund Arthur.
Pidcock, Ernest Elvidge.
Rendall, Arthur Reginald.
Riley, Norman.
Risley, Benjamin George H.
Robertson, James Linford R.
Rowe, Wilfred Stuart.
Sankey, George Ronald, B.A.
Speirs, William Edward
Squire, Major.
Stark, Gordon Alexander.
Stepheng, Robert John
Stevens, Frank Gladstone.
Straughan, Ronald John.
Thorpe, Donal Winton.
Tomlinson, Sydney Frederic.
Turner, Wilfrid.
Turton, Harold John.
Valentine, Percy William S.
Vezey, John Ricketts.
Vivian, William Aubrey.
Wallace, Charles Cameron.
Webb, Leonard.
Wills, William Henry.
Woods, Maurice Geoffrey.
Youle, Frederick.

Associates.

Falmouth, The Rt. Hon. the Viscount.
Jennings, Ernest John.

TRANSFERS.

Associate Member to Member

Allen, Richard Gilbert.
Atkinson, Reginald Charles.
Bailey, William Joseph.
Cruickshank, William.
Drummond, Bernard Gilbert.
Fraser, James.
Gilbert, Alfred Brawn.
Jolley, Leonard Benjamin W., M.A.
Nichols, Arthur Robert.
Partridge, Thomas Teil.
Powell, William Henry.
Twells, Walter Edgar.
Wilby, Ernest John.
Wise, George Macdonald.

Graduate to Associate Member.

Bennett, John Ernest, B.A.
Hobgen, Leslie Burgess.
Monkhouse, Walter Isaac.
Richards, Cleveland Garfield.
Riley, Thomas.

Student to Associate Member

Gates, Reuben.

Student to Graduate.

Crowder, Samuel Goddard.
Fuke, Francis Cecil.
Grad, Charles.
Hollin, Archibald Stewart.
Orrell, William.
Walker, Albert.

A paper by Mr. F. P. Whitaker, Member, entitled "Rotary Converters, with special reference to Railway Electrification" (see page 501), was read and discussed and the meeting adjourned at 8 p.m.

20th MEETING OF THE WIRELESS SECTION, 1 MARCH, 1922.

(Held in the Institution Lecture Theatre.)

Professor G. W. O. Howe, D.Sc., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting of the Wireless Section held on the 1st February, 1922, were taken as read, and were confirmed and signed.

A paper by Messrs. E. B. Moullin, M.A., and L. B. Turner, M.A., Member, entitled "The Thermionic Triode as Rectifier" (see page 706), was read and discussed and the meeting terminated at 7.30 p.m.

679th ORDINARY MEETING, 2 MARCH, 1922.

(Held in the Institution Lecture Theatre.)

Mr. A. A. C. Swinton, F.R.S., Vice-President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 16th February, 1922, were taken as read, and were confirmed and signed.

The following list of donors to the Benevolent Fund was taken as read and the thanks of the meeting were accorded to the donors.

Benevolent Fund.—C. E. Acock, B. N. Adams, G. H. Adams, P. R. Adams, W. J. Addison, I. M. E. Aitken, W. Aitken, H. Alabaster, D. W. Aldridge, R. Alexander, A. H. Allen, C. Allen, J. T. Allen, P. R. Allen, R. G. Allen, T. P. Allen, A. W. Allkins, W. R. Alston, A. A. Anderson, R. Anderson, R. C. A. Anderson, A. Andrews, O. M. Andrews, R. Andrews, R. Ardis, A. N. Arman, J. M. Armstrong, R. E. Armstrong, C. Arnold, J. W. Arthur, R. H. H. Ash, J. Ashmore, J. W. Astley, C. J. Aston, R. E. Atkins, Ll. B. Atkinson, O. L. G. Aust, N. J. Austin, J. F. Avila, Mrs. Ayrton, S. Badcock, A. R. E. Bailey, D. E. Bailey, A. C. Baker, G. H. Baker, Brig.-Gen. W. Baker Brown, F. J. Baldwin, O. H. Baldwin, W. L. Baldwin, G. Balfour, T. J. Ballard, P. E. Bamford, W. Banks, H. Bannister, B. Barber, E. B. Barnett, P. C. Barrand, C. Barry, F. T. Bartho, H. E. Bartlett, G. C. Bass, R. W. Bassil, G. R. Battle, J. Batty, E. Bawtree, H. E. I. Bax, G. B. Bayley, R. F. H. Bayspoole, M. Beales, E. Bealing, H. Beanland, A. T. J. Beard, J. R. Beard, A. H. Beatty, A. W. Beaumont, E. A. Beavis, J. T. Bedford, R. Bedford, A. T. S. Beebee, R. H. Belchem, G. G. Bell-MacIntosh, W. A. Benger, A. E. Bennett, A. W. Bennett, C. H. Bennett, H. W. J. Bennett, A. W. Beuttell, H. Bevis, J. W. Binns, K. W. Birks, D. H. Bishop, J. Rutherford Blaikie, R. S. C. Blance, N. C. Blazey, R. Blennerhassett, J. Bloome, T. D. Boldy, F. Bolton, E. H. Bond, A. F. Bound, E. Braathen, I. Braby, W. W. Bradfield, J. B. Braithwaite, H. P. Bramwell, G. Brander, F. D. H. Bremner, H. Brennan, A. S. Brereton, W. E. Bridgman, W. R. O. Bridgeman, R. E. Bristow, H. R. Broadbent, S. K. Broadfoot, J. Brodie, E. N. Bronsdon, L. G. Brough, C. W. Brown, E. Brown, H. Brown, James Brown, V. A. Brown, W. Brown, W. C. Brown, A. W. Browne, W. H. Brownjohn, W. Brumwell, F. Bryan, R. H. Bryans, T. W. Brydon, H. L. Buckman, F. La T. Budgett, E. H. S. Bullen, C. H. Bulman, V. A. M. Bulow, N. K. Bunn, W. C. Burbridge, A. B. Burgess, A. F. Burgess, W. Burgess, J. Burke, H. J. Bushell, J. M. Butcher, W. M. H. Butcher, A. S. Butler, E. S. Byng, J. M. Calder, K. A. Cameron, A. C. Campbell, E. Campbell, H. S. Cannon, F. W. Capper, S. Carlisle, H. S. Carnegie, W. B. H. Carr, W. N. Carson, E. Carter, W. J. I. Casewell, H. J. Cash, C. V. Cassal, R. Cavill, S. Chadwick, S. Chakravarti, J. W. P. Chalmers, E. L. R. Chamberlain, A. D. Chamen, W. A. Chamen, W. F. Chamen, D. H. W. Channon, D. S. Charles, C. Charman, A. R. Chaytor, H. Cheesman, A. J. Chesterton, G. G. Chisholm, F. F. Christy, B. G. Churcher, P. Churchill, C. W. Clack, E. F. Clark, J. E. Clark, W. H. V. Clark, G. B. Clarke, P. E. Clarke, C. B. Clay, R. L. Cleaver, P. Clegg, H. S. Clifford, E. T. Clifford-Jones, J. K. Clifford-Jones, W. O. Clough, T. Clutterbuck, F. Coates, J. A. Cockburn, R. T. Coe, C. A. Colborn, F. Colburn, F. Cole, F. G. Cole, H. F. Colebrook, A. Collins, W. Collins, J. Colquhoun, L. H. Combe, A. Cook, N. J. Cook, W. K. Cook, W. W. Cook, W. C. Cooke, F. R. Coombes, A. Cooper, C. H. Cooper, W. J. Cooper, W. V. Cooper, F. Cope, A. C. Corner, H. Corner, A. B. Cousins, W. G. Cousins, R. W. H. Couzens, J. R. Cowie, G. Cowling, S. Cowper-Coles, C. H. F. Cox, S. Craig, C. G. Crawford, E. Cripps, C. Crompton, E. H. Crook, S. G. Crowder, L. H. Crowther, C. A. Crutchett, C. E. Cruttwell, W. Cuffley, F. A. V. da Costa, E. E. Daglish, A. C. Dale, I. S. Dalgleish, J. D. Dallas, J. F. F. Dalston, J. W. Damp, C. Dannatt, B. Darby, M. J. Dark, W. N. Darling, A. Davenport, Prof. H. T. Davidge, B. M. J. Davies, G. F. Davies, G. H. Davies, J. H. Davies, N. C. Davies, P. G. Davies, E. S. Davis, A. R. Dawes, E. M. Dawkin, R. L. Dawson, H. F. Deane, F. E. Denné, W. H. Dennis, J. W. Desborough, F. de Steiger, Sir J. Devonshire, K.B.E., C. H. de Warburg, A. E. H. Dinham-Peren, E. Dixon, H. H. Dixon, S. B. Donkin, E. T. G. Donovan, H. S. Double, F. J. Down, J. P. A. Drewry, L. F. A. Driscoll, B. G. Drummond, G. L. Drury, J. Dubbin, W. Duckworth, G. E. Duke, L. Dunbar, C. Duncan, P. Dunsheath, T. R. Dupère, H. Dutton, H. A. Easter, A. C. Eden, F. H. Edwards, L. Edwards, W. G. Edwards, W. J. Edwards, F. P. Egerton, The Electrical Power Engineers' Association, The *Electrical Review* (per E. A. Gatehouse), J. E. Eliades, A. ap-Ellis, C. J. A. Ellis, F. A. Ellis, G. H. Elsden, C. W. Emanuel, S. J. Emerson, J. L. Ensor, B. A. Evans, C. L. Evans, S. L. Evans, L. H. Euler, S. Evershed, G. G. Ewer, G. L. Eynon, W. Eynon, J. A. Fagan, A. E. Falkus, F. C. Faraker, H. Faulkner, R. A. Fearnley, H. Featherstone,

L. E. Felix-Smith, J. D. Ferguson, J. W. Fewtrell, C. E. Field, H. J. Finden, A. H. Finlay, A. J. Fippard, L. B. Firnberg, N. Firth, F. L. Fisher, J. J. Fisher, Prof. J. A. Fleming, J. G. Fleming, W. K. Fleming, G. H. Fletcher, E. W. Flint, L. H. Ford, C. B. Foster, D. S. Foulkes-Roberts, M. W. Foulkes-Roberts, H. C. Fox, H. S. Fox, R. C. Fox, A. H. Foyster, H. G. Frampton, M. R. Francis, S. Francis, H. W. Franks, W. A. Frazer, P. Freedman, W. J. F. Freeland, G. F. Freeman, B. French, P. R. Friedlaender, C. A. Friendship, R. A. Frost, T. Gabbott, F. Gait, J. Galloway, K. C. G. Gandhi, J. C. Garnes, J. A. T. Garrard, W. H. Gatley, A. Gay, A. H. Gay, F. A. Geary, D. W. Gee, K. S. Geipel, T. A. George, D. C. Gerrard, K. C. Ghose, H. E. Gibbard, H. J. Gibson, R. D. Gifford, J. V. Gil, H. W. Gilbert, H. W. Giles, F. Gill, H. Gill, H. A. Gill, M. McA. Gillespie, S. C. Ginno, L. C. Gleaves, A. Glegg, J. B. Glen, F. H. Glover, H. Gobie, L. J. Gooch, P. Good, C. L. Goolding, M. L. Gorham, W. 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A discussion took place on the subject of "Starters," with the following introductory papers :—"The B.E.S.A. Specifications for Starters," by Mr. C. H. Wordingham, C.B.E., Past President; "Electric Motor Starters," by Mr. J. Anderson, Member (see page 619); "Some Notes on the Design of Liquid Rheostats," by Mr. W. Wilson, B.E., M.Sc., Associate Member (see page 196).

The meeting terminated at 8.20 p.m.

680TH ORDINARY MEETING, 16 MARCH, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 2nd March, 1922, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

A paper by Mr. J. G. Hill, Associate Member, entitled "Phantom Telephone Circuits, and combined Telegraph and Telephone Circuits, worked at Audio Frequencies" (see page 675), was read and discussed and the meeting terminated at 7.55 p.m.

PHANTOM TELEPHONE CIRCUITS, AND COMBINED TELEGRAPH AND TELEPHONE CIRCUITS, WORKED AT AUDIO FREQUENCIES.

By J. G. Hill, Associate Member.

(*Paper first received* 18*th October*, 1921, *and in final form* 28*th April*, 1922; *read at* The Institution 16*th March*, 1922.)

Summary.

The superposing of additional circuits on telegraph and telephone conductors, so as to obtain two or more channels of independent communication from the same physical circuit, now occupies a very important place in the design of such circuits.

The loading of telephone circuits, combined with the use of thermionic amplifiers in them, now renders it possible to provide efficient long-distance telephonic communication—including the provision of phantom circuits—on small-gauge conductors in underground cables carrying a large number of circuits. The provision of these cables involves the gradual replacement of overhead open telephone circuits in a large measure, and constitutes a revolution in modern circuit provision. The object of this paper is to review the present position of the art as applied to superposed circuits worked at audio frequencies.

The theory of simultaneous telegraph and telephone working on the same circuit is first dealt with, and the limitations of this method of working are stated.

The comparative efficiency of side and phantom circuits is then dealt with, and the principal problems arising from the loading and relaying by amplifiers of phantom circuits are outlined. The solution of the problems is indicated.

Finally an appendix is given, dealing with the derivation of formulæ for the calculation of electric wave filters, for application to the circuits dealt with.

Introduction.

The problem of utilizing telegraph and telephone circuits to transmit two or more simultaneous electrical communications over one circuit without interference between them, has from an early date occupied the attention of those interested in telegraphy and telephony. During the past few years a considerable development of some of the methods employed has taken place with far-reaching results; and the object of this paper is to review the present position of the subject so far as the simultaneous transmission of telegraph signals and speech, at normal frequencies, and of phantom telephone working at such frequencies are concerned.

In view of the very wide range of the problems involved it will be possible to deal only very briefly with them. The methods most generally employed to provide extra channels of telegraph or telephone communication may be classified under the following heads:

(1) The Impedance or Retardation method of combined telegraphy and telephony over the same wire or wires.

(2) The Equipotential method of providing simultaneous channels of telegraphic and telephonic communication over the same wires, and the application of this method to the balancing of telephonic relayed circuits.

(1) Impedance Method of Simultaneous Telegraph and Telephone Working Applied to Single-Wire Working.

This method was first introduced by F. Van Ryssel-berghe,* a Belgian telegraph engineer, in 1882. Combined working is rendered possible by the different impedance of inductance coils and condensers respectively to high- and low-frequency currents. The action depends upon the fundamental difference of telegraph Morse signals and telephone speech currents.

Definition of telephone and telegraph signals.

(*a*) *Telephone signals.*—The voltages and currents produced in a telephone circuit by the voice are assumed to vary in a simple harmonic manner. The voice covers a wide range of frequencies varying, say, between 100 and 2 500 periods per second; the mean frequency for purposes of calculation is taken at 800 periods per second.†

(*b*) *Telegraph signals.*—In the Morse code these consist of "dots" and "dashes." In hand signalling at the normal rate of 30 words per minute a dot has a duration of 1/12 second and this will be used as a basis of comparison.

Explanation of the electrical action in an impeded combined telegraph and telephone circuit.—If an electric condenser of sufficient capacity (say 5 μF) is placed in series with a telephone receiver in an ordinary telephone circuit, the attenuation of speech currents due to the condenser is so small as to be only just perceptible to the ear. The impedance of the condenser to very low-frequency currents is, however, very high. On the other hand if a suitable inductive impedance be placed in the line lead of a telegraph set the speed of telegraph signalling is slowed down, but it is still possible to signal at hand speed on the telegraph circuit. In addition to these direct actions in the telegraph and telephone circuit, and other direct actions which will be shortly described, the action of each circuit on the other requires consideration. The reduction in the rate of rise of the telegraph signals reduces the normal

* British Patents Nos. 1 303 and 2 466 of 1882, and 3 621 and 5 503 of 1883.

† "Conference Internationale des Techniciens des Administrations des Télégraphes et Téléphones de l'Europe." Paris, 1910. *Comptes Rendus*, p. 99.

tendency of those signals to cause disturbance in the telephone apparatus via the condenser, in view of the simple fact that the disturbing signals vary in intensity in proportion to the rapidity of the rate of change of voltage at the terminals of the condenser. The retarding device in the telegraph circuit, however, has a very high impedance to telephone speaking currents at the mean frequency of speech, and this high impedance acts beneficially as regards the transmission of speech, by reducing the transmission loss due to the telegraph apparatus acting as a shunt to speech currents. The disturbing effect of speech currents on ordinary Morse telegraphic apparatus is absolutely negligible.

Van Rysselberghe System.

The working of this system depends fundamentally on the actions described. A high inductive impedance RL is placed in the path of the telegraph apparatus and a condenser C in the path of the telephone apparatus, the two sets of apparatus being joined in parallel and connected to the line as indicated in Fig. 1 in which both ends of the circuit are shown. A single-current circuit is shown for simplicity, but double-current working is generally used.

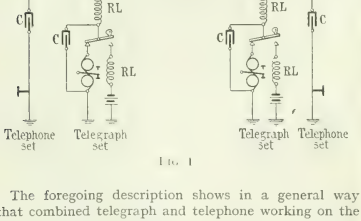


Fig. 1

The foregoing description shows in a general way that combined telegraph and telephone working on the same wire is possible, but it is of interest to study more closely the effect of the inductive impedance and the condenser in order to find to what extent (if any) the retarded telegraph signals cause disturbance in the telephone set, and, further, how far the retardation affects the telegraph signals themselves as regards both shortening them and slowing down the rate of signalling. These matters will now be investigated.

In commercial combined telegraph and telephone circuits the apparatus arrangements are complex, as may be seen by inspection of the diagrams here given, and in addition the electrical action is materially complicated by the fact that the permeability of the iron cores and the effective resistances of the telegraph apparatus in circuit change materially with different current strengths. For these reasons experiment is usually preferred to calculation in determining the best values of the inductance and capacity required. The fundamental theoretical effect of the devices introduced to control the rate of rise of the current may, however, be studied with advantage from the mathematical point of view in the relatively simple circuit shown in Fig. 2.

Let E = a constant applied voltage at A.
v = the voltage at the terminals of the condenser at the time t.
R = the resistance of the retardation coil.
L = the inductance in henrys of the retardation coil.
R_1 = the unvarying resistance of a long line supposed to be non-inductive.
C = the capacity of the condenser in farads.
t = the time in seconds after the application of the voltage E to the circuit.

Then the equation connecting the voltage v with the time during the transient period when the E.M.F. is rising from zero to its steady value E, is

$$\frac{d^2v}{dt^2} + \left(\frac{R}{L} + \frac{1}{CR_1}\right)\frac{dv}{dt} + \left(\frac{R}{CLR_1} + \frac{1}{CL}\right)v = \frac{E}{CL} \quad . \quad (1)$$

The corresponding equation for the value of v at any instant t after the application of E, is

$$v = \frac{ER_1}{R + R_1}\left[\left(\frac{1}{2} - \frac{\alpha}{2\beta}\right)e^{(-\alpha+\beta)t} - \left(\frac{\alpha}{2\beta} + \frac{1}{2}\right)e^{(-\alpha-\beta)t} + 1\right] \quad (2)$$

where

$$\alpha = \frac{1}{2}\left(\frac{R}{L} + \frac{1}{CR_1}\right) \text{ and } \beta = \frac{1}{2}\sqrt{\left[\left(\frac{R}{L} - \frac{1}{CR_1}\right)^2 - \frac{4}{LC}\right]} \quad . \quad (3)$$

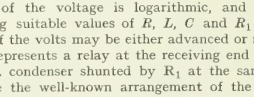


Fig. 2

If $R/L = 1/CR_1$ and $R = R_1$ the equation for v may be written

$$v = \tfrac{1}{2}E[1 - \sqrt{2}e^{-t/CR}\sin(t/CR + \tfrac{1}{4}\pi)] \quad . \quad . \quad (4)$$

In any case if β is imaginary the equation assumes a form similar to (4).

Examination of these equations shows that the rate of rise of the voltage is logarithmic, and that by arranging suitable values of R, L, C and R_1 the rate of rise of the volts may be either advanced or retarded. If RL represents a relay at the receiving end of a line and C a condenser shunted by R_1 at the same point we have the well-known arrangement of the shunted condenser as may be seen from Fig. 2. Fig. 3 gives an oscillogram of the normal rise of current in an unshunted Wheatstone telegraph receiver, and Fig. 4 shows the more rapid rate of rise obtained by adding the shunted condenser to the same apparatus, the adjustment being made to produce a signal as nearly square (flat-topped) as possible.

On the other hand, in order to produce the retardation which is desired in a combined telegraph and telephone

circuit, the following values which have been actually used may be taken as an example:

$R = 50$ ohms
$L = 20$ henrys
$C = 5$ microfarads

If the value of the line resistance R_1 be 500 ohms, the rate of rise is now greatly retarded as compared with Fig. 3. The variation of the voltage at the condenser terminals with time is shown in Fig. 5. It is evident from these examples that the values of R, L and C must be carefully chosen. It is further evident

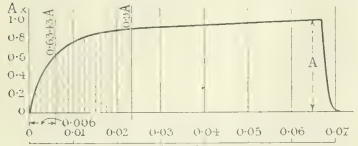


FIG. 3.

from the general equation (2) that in order to produce the least voltage at any instant t, E must be as small as the satisfactory working of the telegraph circuit will permit. It should also be noticed that although the value of R should be small in order to give a small time-constant yet the amount of v becomes less as R becomes greater, but of course the greater R may be unfavourable to the telegraph circuit.

Although the more complex apparatus arrangement shown in Fig. 1 causes the effects just described to be modified, experiment clearly demonstrates the fact that relatively large values of L and C give good results.

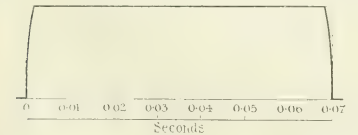


FIG. 4.

It will now, however, be shown that it is not practicable by an arrangement such as that shown in Fig. 2 to eliminate entirely the disturbing effect of ordinary Morse signals in the telephone circuit, due to the rate of change of voltage at the terminals of the condenser.

An examination of Fig. 5 shows that in the first 1/100 second after the application of the E.M.F. the volts have risen to 18 per cent of their final value, notwithstanding the heavy retardation, and such a rapid change of voltage would, with the voltages used in the ordinary Morse system, give rise to a click in the telephone receiver.

If this is compared with the rapid rise of an ordinary Morse signal, however, it is at once seen that the retardation which has just been examined has slowed down the signal considerably. Fig. 3 shows a record of a normal signal passed through a Wheatstone receiver at a speed of 18 words per minute. In this case, in the first 1/100 second the current has risen to about 0·75 of its full value, which is a much more rapid change than the case previously dealt with.

In order to see the effect of this changing current on the telephone apparatus, it should be noted that the telephone receiver has a marked sensitivity in the neighbourhood of 800 to 1 000 periods per second. If the maximum current passing through the Wheatstone receiver is 10 mA there is a rate of change of over 2 mA in the first 1/800 second (see Fig. 3) and it is known that a current of this magnitude

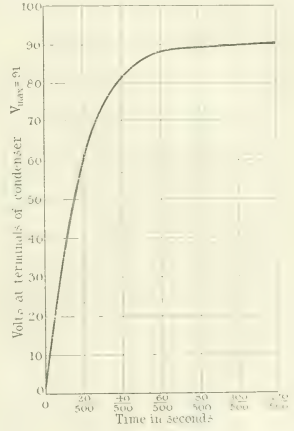


FIG. 5.

will produce a pronounced click in a telephone receiver. The current attains 9/10ths of its maximum value after one-third of the full duration of the signal has elapsed. In the absence of combined telegraph and telephone working it is frequently necessary to increase the rate of rise of signals instead of retarding them, and the means of doing this have been dealt with.

It may be remarked that the retarding device RL in Fig. 1 does not protect the telephone superimposed apparatus in the same circuit from the disturbing effects of telegraph induction from contiguous uncomposited telegraph circuits. Inductive disturbances from such circuits pass partly through the telephone apparatus owing to the fact that the retarding inductance is in the path of the telegraph apparatus only. On this account heavy induction from uncomposited contiguous telegraph circuits may affect the composited circuit.

The remedy is to place retarding devices in the circuits which give rise to the disturbance.

Effect of the Retarding Devices on the Rate of Telegraph Signalling in Aerial Circuits.

Electric waves travel on unloaded aerial copper wires of small resistance with a speed approaching that of light, whilst in heavily loaded underground circuits the speed may be reduced to 8 000 miles per second. The rate of telegraph working is largely influenced, however, by the electrical sensitivity of the apparatus employed, as well as its mechanical inertia, so that in practice the rate of working depends on the combined apparatus and line. From another point of view it also depends on the technical nature of the service utilized. For example, in simplex working a higher all-round speed per channel is possible than in duplex working, and, again, a higher speed is obtainable per channel in duplex working than in quadruplex working. Further, it does not follow that the actual speed of transmitting signals will give a proportionately economical result, for the question of the operator's time in preparing the message for transmission at the sending end and in preparing it for delivery at the receiving end enters into the matter, some systems involving more time for this than others.

For the purpose of the present problem, however, the rate of rise of each signal is of immediate importance. As an example, consider an aerial-line Morse Wheatstone circuit. It would be possible under the most favourable conditions to obtain a speed of 600 words per minute from this system, but it is preferred to work at a speed which can generally be maintained with ease under unfavourable conditions, and 200 words per minute is frequently found to be convenient; this is equivalent to 80 dots per second, so that a signal would last only 1/80 second. Referring to Fig. 5 it will be seen that the voltage rises to only about one-third of its maximum value in that time, and it would be impracticable to add a heavy retardation in such a circuit. In practice, with the amount of retardation necessary to reduce the noise in the telephone sufficiently for satisfactory working, and bearing in mind the necessity for keeping the voltage of the telegraph circuit as low as possible for the same reason, experiment shows that 60 words per minute on an overhead line working duplex can be obtained only under the most favourable conditions. It should be mentioned in this connection that if too much inductance is used in the retarding device the telegraph signals may stick and be sluggish. In order to provide a working margin of safety the Van Rysselberghe system is in fact generally worked only at hand speed. If this is assumed, electrical filters (see Appendix) may be used to cut off the currents of higher disturbing frequencies (see the example on page 690).

It may be pointed out that the introduction of the retarding device is further likely to cause difficulty in balancing telegraph duplex circuits, owing to the necessity of balancing in the compensation circuit of the duplex, the effects of the retardation added to the line. In order to minimize this difficulty it is found in practice that if the windings of the retardation coil are joined up so as to oppose each other, balancing is much easier, whilst the telephone circuit may still be worked. The best position for the retardation coil in duplex circuits is in the lead common to the line and compensation circuit.

In addition to the rate of rise of the current, telegraph signals have a periodicity, the wave-form being generally of a complicated nature. A Morse signal has a low periodicity, and advantage may be taken of this fact so to tune anti-inductive apparatus as to eliminate or reduce inductive disturbance within a given band of frequencies, when the frequency of the disturbance is sufficiently high.

The foregoing facts show the limitations of the system of combined telegraphy and telephony just dealt with.

Method of Telephone Ringing.

The ordinary magneto generator, which is of low frequency—about 17 periods per second—is liable to interfere with the telegraph apparatus, and for this reason telephone signalling at a higher frequency is desirable. The best frequency is one which is high enough to avoid interference with the telegraph apparatus, and at the same time is efficient for actuating the sensitive type of relay used. The frequency which is found to be high enough for these purposes should not be exceeded, owing to the fact that high-frequency currents cause inductive disturbance to other circuits; actually, a frequency near 150 periods per second is found to be suitable. As a general rule some form of interrupter or buzzer is used to generate the calling current on all types of composited circuits. Sometimes an interrupted direct current, actuated on the principle of the electric call-bell, is passed through the speaking induction coil in order to convert the signals into an alternating current.

The receiving device may be a loud form of telephone receiver with a horn, or a vibrating relay tuned to the sending frequency, which brings a calling signal into operation.

An arrangement developed by the Western Electric Co. is as follows: The generator is of the vibrating-bar type, the natural frequency of which is 140 periods per second. The relay designed to receive the signals consists of a bar tuned to the same frequency, and actuated by the received currents, which pass through bobbins wound on pole-pieces on each side of the reed. A light contact spring rests normally on the reed and makes contact with it. When the reed vibrates the contact is broken intermittently and this can be made to release a relay connected in a local circuit.

The receiving apparatus must be so designed that it will not respond to the telegraph signals.

Grade of Telephone Circuit Obtained.

A relatively poor circuit, unsuited for working on the long-distance system, is usually obtained. This is due to several causes. A telegraph line wire may be iron and will, moreover, always be subject to a certain amount of disturbance. Generally the conductor will

not be of a high-grade telephone type. If such a circuit is extended, complications arise, and transformers, involving further transmission loss, become necessary. This system works most successfully on relatively short circuits which do not require to be extended. If, however, the device is installed on a high-grade copper conductor, the speaking range may be considerably increased.

Since Van Rysselberghe's system numerous inventors have exercised their ingenuity in producing the same result by different means. As well-known examples in this country may be cited the Phonopore circuit, patented by Mr. C. L. Langdon-Davies (British Patent No. 10 990 of 1884), and the Turchi-Brunè system (British Patents Nos. 7 585 and 22 388 of 1903).

Impedance device.—To give an idea of one of the many variations on the Van Rysselberghe method,

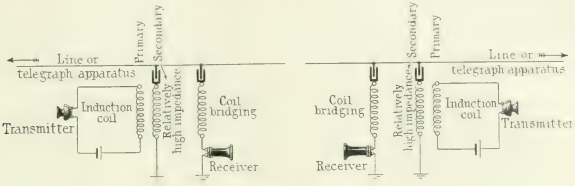


FIG. 6.

Fig. 6 has been prepared. This shows an arrangement in which a bridging coil is placed in series with the receiver. When used in local circuits with a powerful transmitter it is capable of giving excellent results in circuits of suitable length. This apparatus suppresses noise by sacrificing transmission efficiency in the receiving circuit, but if the receiver be made insensitive to the extent that it cuts down the volume of speech to the same degree as 20 miles of standard cable—which usually suffices to reduce loud noise to tolerable limits—there is still a possibility of utilizing the arrangement on many circuits, seeing that the commercial limit of speech is not reached in a quiet room until a total of 46 miles of standard cable is in circuit. It is of course desirable to keep far within that limit, and the margin available often permits this to be done on local circuits which do not require to be extended, when used in conjunction with a powerful transmitter.

It should be noticed that "side tone" which painfully affects the ear when loud-speaking telephones are used in standard sets is practically reduced to negligible proportions, owing to the circuit arrangement in this and similar cases.

The Fullerphone.—This well-known device occupies a prominent place in the literature of the subject, but as it has already been fully described reference should be made to Major Fuller's paper.*

* "The Fullerphone and its Application to Civil and Military Telegraphy," *Journal I.E.E.*, 1919, Supplement to vol. 57, p. 29.

Composited Circuits.

Fig. 7 shows an arrangement used in England and elsewhere for utilizing the two wires of a double-wire circuit to form two duplex circuits. This arrangement is known as composited working. In this country the arrangement is sometimes used to superpose telephone call wires worked by telegraph, upon junction circuits worked on the common battery system (see Fig. 7), or, alternatively, one wire is used as a telegraph call wire, and the other for automatic signalling on the junction circuit. In such a case each set of apparatus bridged on the telephone circuit involves a transmission loss, which is usually not less than one mile of standard cable, and may possibly exceed this figure. The loss is increased when similar circuits are extended to one another; it should therefore be ascertained, before doing this, whether the circuits have the necessary transmission margin.

It may be mentioned that simplexed and composited sets have been used in this country for many years. (A simplexed circuit is a telegraph circuit worked in parallel over the two wires of a telephone circuit.) As an example I find that as far back as 1908, 200 circuits on the simplexed system were in use in this country. At the same time a large number of circuits were in use for local telephone circuit working on a method devised by Mr. W. J. Medlyn which has largely been used in this country for this purpose and is described in Post Office Technical

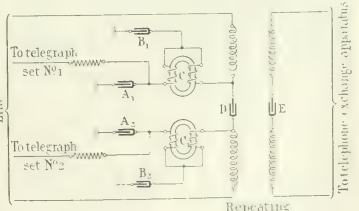


FIG. 7.

Circular E No. 10. The theoretical diagram is shown in Fig. 8 and the explanation is as follows: If on a short section of a pole route carrying a long main-line telegraph circuit, we have also a local single-wire circuit which it is desired to convert to telephone working, such a circuit may be converted to double-wire working with little cost in the main-line section by utilizing in that length a long-distance telegraph circuit to form the second wire of the local pair. The local single-wire circuit and the telegraph circuit are crossed at intervals to give immunity from inductive disturbance due to contiguous telegraph circuits, and transformers are connected as shown. The section between the transformers is the double-wire telephone circuit. Telegraph signals pass in parallel over the double-wire telephone circuit thus formed, entering and leaving the double-wire section at the centre point of the transformers. By this method the continuity of the telegraph circuit is not interrupted. The working of such a telephone loop is not disturbed by a superposed telegraph circuit if the A and B wires are of the same material and gauge. In the case shown, the telephone circuit after leaving the main line is run on a single wire which is connected to the transformers as shown. The possibility of using the single wire depends on local conditions.

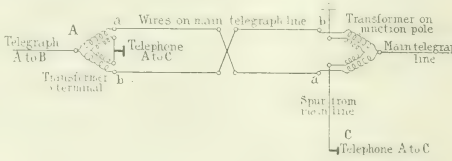
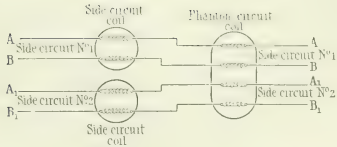
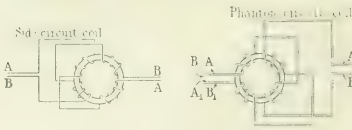


FIG. 8.



Theoretical arrangement of loading coils in circuit.



Arrangement of loading-coil windings.

FIG. 9.

(2) Telephone Circuit Phantom Working.

The well-known equipotential method of superposing now to be dealt with is of great importance and utility and of very wide application. Fig. 10 furnishes an example of the system. The earliest patent specification in this country covering this form of superposing is that of Mr. F. Jacob (British Patent No. 231 of 1882).

Relative Efficiency of the Side and Phantom Circuits in Aerial Lines.

The relative transmission efficiency of side and phantom circuits in aerial lines depends essentially on the arrangement of the wires on the poles. Every circuit has, of course, four electrical constants, namely, resistance, leakance, capacity, and inductance. Effective, uniformly distributed values at alternating-current voice frequencies are here assumed.

The relative transmission efficiency of both side and phantom circuits is inversely proportional to the real part β of the complex attenuation constant $\beta + j\alpha$ and may be found from the following well-known formula:

$$\beta + j\alpha = \sqrt{(R + j\omega L)(G + j\omega C)} \quad . \quad . \quad (5)$$

where β = real part of attenuation constant,
α = wave-length constant,
R = effective resistance per unit length,
L = effective inductance per unit length,
G = effective leakance per unit length, and
C = effective capacity per unit length.

The transmission efficiency is also affected by the impedance of the circuit. In the case of an electrically long line the quantity Z_0 is usually known as the characteristic impedance: and

$$Z_0 = \sqrt{\left(\frac{R + j\omega L}{G + j\omega C}\right)} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The minimum attenuation constant in unloaded circuits is theoretically attained when we have the relation

$$LG = CR \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

In phantom circuits where two wires are joined in parallel the resistance is generally half that of the side circuit, and the leakance double that of the side circuit. If, therefore, C is also doubled and L halved as compared with the side circuit, equation (7) is satisfied and we have the conditions for minimum attenuation for both side and phantom circuit.

Now R and G are generally fixed for any combination of side and phantom circuits, and have the relative values given. Whether the minimum attenuation constant is in question or not we have equal transmission efficiency, if, when the side-circuit constants are C, G, L, R, the phantom-circuit constants are $2C$, $2G$, $\frac{1}{2}L$, $\frac{1}{2}R$, and this furnishes a criterion for the comparison of transmission efficiency. As a general rule the capacity and inductance have not the proportion shown. As is well known, the circuit inductance and capacity vary according to a logarithmic function of the distance apart of the wires. The nearer together the wires of the side circuit are, and in the case of the phantom circuits the nearer together the side circuits —which constitute the limbs of the phantom circuit— the greater the capacity and the less the inductance, and vice versa. As a general rule the transmission efficiency of a circuit is improved by separating the wires more widely, because the normal capacity of a circuit as compared with its inductance is in excess from the point of view of the capacity and inductance required to produce the minimum attenuation constant. The separation of the wires tends to bring both the capacity and inductance nearer to the proportion that satisfies the minimum attenuation constant. There is, however, an accompanying disadvantage here, because unless a circuit is perfectly balanced the separation of the wires increases inductive disturbance from sources of disturbance outside the superposed four-wire system.

Wires arranged on the Pole-arms at the Four Corners of a Square. Effect on Transmission.

The relative transmission efficiency of two common arrangements will now be examined. If the four conductors of a phantom-circuit combination are arranged on the pole-arms so as to form a square as seen end-on, two wires being arranged on one arm and the other two immediately below on another arm, the side circuits being the diagonals of the square, it can be shown theoretically that the relative values of capacity and inductance of side and phantom circuits are such that the capacity of the phantom circuit is greater than twice the capacity of the side circuit, and that the inductance of the phantom circuit is somewhat less than half that of the side circuit. It follows that the transmission efficiency of the phantom circuit is a little less than that of the side circuit.

The arrangement described is that which has hitherto been adopted in this country, the anti-inductive arrangement consisting in transposing the position of each wire on the pole-arms so that a complete revolution takes place between every four poles.

An alternative anti-inductive method to that described, still retaining the square formation on the four pole-arms, is to run the wires straight for a given length—say half a mile—and then cross them at regular and equal intervals of half a mile. This method is being also adopted in this country. The transmission efficiency of the two anti-inductive methods described, both being in square formation, is nearly equal. Experiments in this country showed a difference of 2 per cent in the attenuation constant, being less to that extent in the case of the wires run straight.

Four Wires arranged at Equal Horizontal Distances on the same Pole-Arm. Effect on Transmission.

The two side circuits being formed of adjacent wires from left to right in each case and supposed to be crossed at equal intervals, it can be shown that the inductance L of the phantom circuit is greater than one-half that of the side circuit, and that the capacity C of the phantom circuit is less than twice the capacity of the side circuit. As a consequence the phantom circuit has a lower attenuation than that of the side circuit, and this is verified in practice.

Table 1.

Capacity Formulæ for Aerial Lines.*

Wires arranged in square formation.

Side circuit.	Phantom circuit.
$C = \dfrac{1}{4 \log (d/r)}$	$C = \dfrac{1}{2 \log (d/2r)}$

Inductance formulæ.

$$L = 4 \log (d/r) + \mu \qquad L = 2 \log (d/2r) + \mu/2$$

r is the radius of a conductor, d is the distance between the wires of the side circuit, and μ is the permeability of the conductor, assumed to be constant.

Wires in a straight line on the same arm at equal distances, the wires composing the side circuit in each case being crossed with each other at regular intervals.

Side circuit.	Phantom circuit.
$C = \dfrac{1}{4 \log (d/r)}$	$C = \dfrac{\log (\sqrt{3}d/2r)}{2 \log (d/r) \log (3d/r)}$

Inductance formulæ.

$$L = 4 \log (d/r) + \mu \qquad L = 2 \log (3 \cdot 46\, l/r) + \mu/2$$

Relative Efficiency of Side and Phantom Circuits in Unloaded Underground Circuits of the Multiple Twin Type in Air-space Cables.

The first patent for this type of cable was that of Dieselhorst and A. W. Martin (British Patent, 12 526 of 1903).

In these cables the relative transmission efficiency of side circuits and phantom circuits, respectively, follows the general rule, and depends on the relative values of their inductance and capacity. Owing, however to the fact that the wires making up the side and phantom circuits in cables are closely packed

* See "Telephonic Transmission of Superimposed Circuits," by Kazukiyo Ogawa, Researches of the Electrotechnical Laboratory, Department of Communications, Tokyo, Japan, July, 1919.

together, the capacity is relatively much larger, and the inductance much smaller than in the case of aerial wires, for the reason already given, and consequently the transmission efficiency of such unloaded circuits is much less than those of the same conductor weight in aerial lines [see Formula (5)]. As a rule the capacity of telephone circuits in cables containing a large number of wires is predicted from experiment, since it is largely affected by a factor depending on the form and dimensions of the cable. Telephone air-space paper cables for phantom working are usually made up on the "multiple twin" formation, i.e. two telephone pairs are twisted together to form a phantom pair, and the relative capacity of side and phantom circuits may vary largely. The lay of the conductors is varied in

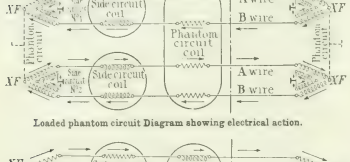

Loaded side and phantom circuits. Explanatory diagram.
XF
Side circuit coil
A wire
B wire
Phantom circuit coil
S
Loaded phantom circuit Diagram showing electrical action.
P
Explanation of symbols
Telephone
Direction of current
Current passing through coil or transformer windings in inductive direction
Current passing through coil or transformer windings in non-inductive direction
Dotted lines indicate no current in that part of the circuit
Solid lines show that a current is flowing
Transformer
S illustrates side circuit, and P phantom circuit working

FIG. 10.

the usual way. Experiment on recent cables shows, however, that the capacity of a phantom circuit has usually a mean value approximately 50 per cent in excess of that of the side circuit. The natural inductance in telephone cables containing small-gauge conductors is so small as to be nearly negligible and will be left out of consideration. Artificial inductance is, of course, generally added to underground circuits which form part of the trunk or long-distance system, and the problems of circuit balance presented by these loaded circuits will be dealt with further on. On account of the relatively small capacity of the phantom circuit in such cables as compared with the capacity of the side circuits, the phantom circuit is of a higher transmission efficiency than the side circuit, so that by superposing we actually obtain an additional circuit which is more efficient than the circuit on which it is superposed.

Extension of the Phantom Principle.

It should be noted that it is possible to carry the principle of phantoming further, and to obtain a second phantom metallic circuit by combining two four-wire cores and twisting them together in the same way as the two side circuits are twisted in order to form an ordinary phantom circuit. Eight wires would evidently be necessary for such a circuit, and the principle may theoretically be continued, using 16 wires, 32 wires, etc., for successive phantom circuits until the number of combinations is exhausted. In practice, however, phantom circuits are limited to four-wire combinations at present.

Submarine Cables: Capacity and Transmission Relations.

As regards submarine cables, which frequently contain only four wires, there is no difficulty in calculating the capacity, which in the case of gutta-percha insulated cables is obtained from the formula

$$C = \frac{A}{\log_{10}(D/d)} \quad . \quad . \quad . \quad . \quad . \quad (8)$$

where D is the outer diameter of the gutta-percha, d the diameter of the copper conductor, and A is a factor proportional to the dielectric constant. The dielectric constant varies between 3 and 4. A figure often used is 3·6, and in that case A becomes 0·16 and the formula then gives the capacity of a single wire per nautical mile.

Owing to their immersion in the sea the four wires of such cables are screened, and this simplifies the capacity relations; for example, the capacity of a double-wire circuit is one-half that of a single-wire circuit, and the capacity of the metallic four-wire phantom circuit is twice that of the side circuit. The capacity of the four-wire earthed phantom circuit is four times that of a single earthed wire. As a consequence of these capacity relations a metallic loaded phantom circuit has approximately the same efficiency as the side circuit. The earthed phantom circuit, however, is materially less efficient than the other two circuits, owing to the increased effective resistance, which is observed in such circuits—e.g. an increase of about 2·5 ohms per naut per wire at 800 periods per second—owing to the interaction between the field of the conductor and the metallic sheath of the cable, and the effect of the return path consisting of sea water. (For fuller details see Sir W. Noble's paper referred to on page 684.) It will be remembered that the impedance of the side and phantom circuits varies according to formula (6). The four wires in such a cable are usually arranged in quad formation, the diagonal wires forming the two side circuits and each side circuit forming one limb of the phantom circuit. As seen end-on the four wires are at the four corners of a square. In the case of a four-wire loaded or unloaded submarine cable it is theoretically possible to obtain four telephone circuits without mutual interference. In the case of

coil-loaded circuits two separate coils are used for the phantom circuit at each loading point, otherwise the four-wire earthed phantom circuit would not be loaded. The phantom coil arrangement referred to is the usual loading method of Messrs. Siemens Brothers & Co. in such cases.*

Combined Phantom Circuit and Composited Circuit Working.

It is possible under favourable circuit conditions to combine the loaded phantom circuit, as shown in Fig. 10, with the composited arrangement shown in Fig. 7. For this purpose the telegraph sets arranged as in Fig. 7 may be added to the ends of the two side circuits in Fig. 10. In order to secure a balanced arrangement it would be necessary for all the telegraph sets to have the same impedance at the same end of the line. Such a circuit would be subject to the limitations pointed out in connection with the phantom circuit and the composited circuits. It is believed that an equivalent arrangement is worked in America, but it has not been used in Europe so far as the author is aware.

Transformers in Phantom Circuits.

This apparatus absorbs a certain amount of energy and the effect on telephonic transmission requires consideration. Moreover, the usual signalling frequency is about 1 000 periods per minute, or approximately 17 per second, whereas the mean frequency of speech is taken at 800 periods per second. The design of a transformer of small dimensions to meet both these requirements is difficult, and for that reason there is an advantage in utilizing a frequency within the range of frequencies for which the transformer has been designed. A transformer designed and sold by the Western Electric Co. and known as "type 4006A" is, however, available for this purpose. At a frequency of 133 periods per second it is found to be very efficient for signalling, and it is specially efficient at telephonic voice frequencies.

The Post Office Specification which requires an output of 80 per cent of the input energy at a frequency f such that $2\pi f = 5\,000$, and of 55 per cent at a frequency f such that $2\pi f = 100$, is met by this apparatus; it also fulfils the stringent condition imposed for differential action when currents are sent through the windings in opposite directions.

The transmission loss (core loss) observed in comparative speech tests does not exceed the loss which takes place when speaking through one mile of the standard cable.

It may be mentioned that the method of winding to secure the differential action is one devised by the Post Office.

Other manufacturers also make efficient transformers.

Loaded Phantom Circuits: Electrical Action.

It is assumed that the principles of loading are understood. When the phantom circuit is loaded a separate and extra coil is usually required for it at every loading point (see Figs. 9 and 10). It will be seen that the phantom-circuit coil is so arranged that a current sent round each side-circuit coil in an inductive direction passes round the two halves of the phantom-circuit coil in opposite directions, so that no inductance is produced in the coil. On the contrary, currents flowing in the phantom-circuit coils in an inductive direction pass through the windings of the side-circuit coils in a non-inductive direction. The theoretical electrical action in the loaded side and phantom circuits is shown in Fig. 10 and it is thought that the diagrams will be found self-explanatory.

Relative Transmission Efficiency and Cheapest Combination of Loaded Side and Phantom Circuits in Underground Cables.

The formula for the attenuation of a side and phantom circuit when ωL is great in proportion to R and ωC great in proportion to G, which is the general case, is

$$\beta = \frac{R + \left(\frac{R_1}{L_1} - \frac{G}{C}\right)L}{2\sqrt{\left(\frac{C}{L}\right)}} \quad . \quad . \quad . \quad (9)$$

where R_1/L_1 is the effective resistance of the coil, divided by its inductance. Within practical working limits this ratio can be made constant for a side-circuit coil and for a phantom-circuit coil respectively, the two series of coils (side and phantom), however, being independent and separate; the ratio of the circuit leakance G to the capacity C at a fixed frequency for different values of C is also constant. The other symbols have been already defined. Assuming R_1/L_1 and G/C to be the same for the side and phantom circuits, the same value of β is obtained for both circuits, if the side circuit has double the inductance of the phantom circuit, and if the side circuit has one-half the capacity of the phantom circuit. As shown in the preceding paragraphs, however, the capacity of the phantom circuit in underground cables is only about 50 per cent greater than that of the side circuit, so that the arrangement just described does not hold good.

In practice, the relative efficiency of transmission of the side and phantom circuits is largely determined by commercial conditions as well as electrical possibilities, the main considerations being as follows:—

It is economical to space loading coils as widely apart as possible in order to obtain a given average inductance per mile, but it can be shown that the wider the spacing the more the higher frequencies which enter into the composition of speech are cut off, and beyond a certain cut-off point telephonic speech becomes indistinct and impossible. Owing to the indeterminate nature of the frequencies entering into speech it is necessary to make experiments to determine the widest permissible spacing. The rule hitherto obtaining as a result of experiment in Great Britain is as follows:

$$CDL = 25 \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where C is the capacity of the cable circuit in microfarads per mile, D is the distance in miles separating

* J. G. Hill: "Two Loaded Phantom Circuits in a 4-Wire Submarine Cable," *Journal of the Institution of Post Office Electrical Engineers*, 1914, vol. 7, p. 197.

the coils and L is the inductance of the loading coil in millihenrys. This rule applies to circuits of length, say, not exceeding 350 miles. Beyond that point the upper frequencies are too much attenuated and other phenomena become evident, making it necessary to reduce the inductance without altering C or D in formula (10). Again, in practice it is economical to have only one set of manholes to accommodate both side and phantom loading coils. The most economical arrangement for the two side circuits generally leads to the greatest total economy of the four-wire combination, and the position of the manholes is therefore made to suit the side circuits; this means that there is no choice of spacing for the phantom coils. The only thing that can be done for the phantom circuit is to increase its inductance above the hypothetical value of one-half that of the side circuit up to the limit permissible by the spacing rule, and this procedure gives a phantom circuit having a lower attenuation constant, and therefore a higher transmission efficiency, than the side circuit, usually to the extent of 15 to 25 per cent (owing to the relatively smaller capacity of the phantom circuit and its higher degree of loading).

For a given transmission equivalent—say S miles of standard cable—between two given fixed points, such for example as a transmission equivalent of 15 miles of standard cable between London and Leicester, it is possible to find the cheapest possible combination of loading coil and cable (including side circuits and phantom circuits) which will produce the required transmission efficiency. This is obtained from the formula

$$P = \frac{A}{C}\left(x_2 - 2 + \frac{1}{x_2}\right) + \frac{BxC}{x_2 - 1} \quad . \quad . \quad (11)$$

where

P = the combined cost of one mile of cable pair and its loading,

$A = RP_1$ where R is the resistance of one mile of a known and selected conductor pair and P_1 its cost,

$B = \sqrt{\alpha/R}P_2$ where $x = Lm/L$. Lm is the maximum loading of the conductor of resistance R and L is the loading which when combined with R gives the required attenuation constant β. P_2 is the cost per mile of providing L and includes coils and manholes.

$C = R_1\sigma : 2 \cdot 1(x) - R_2(x_2 - 2 \cdot 1/x_2)$. Here $x_2 = Lm_2/L_2$, which is the maximum loading Lm_2 for R_2 divided by an inductance L_2, which inductance when associated with R_2 in a cable pair gives the required β. R_2 and L_2 are the unknown values which may be derived from x_2.*

Overhearing and Cross-talk due to the Want of Uniformity of the Electrical Constants of the Four Wires in a Phantom Circuit, with Notes on the Method of Eliminating Them.

It will be evident from the preceding description that the circuit arrangement of a loaded phantom circuit is complex. In order to balance such a circuit perfectly the potential in the A and B wires of the side circuits (which are joined in parallel, see Fig. 10) must be equal for all the frequencies of the voice and, unless the impedances of the A and B lines (in magnitude and phase) are equal at all points equidistant from the sending end, the want of electrical balance will result in overhearing if the permissible limits of unbalance are exceeded. Now the loading of the circuits augments the difficulties which may have existed in the unloaded pairs, principally because the circuits have thereby become more efficient carriers of energy, and also due to the shortened wave-length (and this applies both to the circuit in which the overhearing arises and contiguous circuits which transmit the augmented disturbance more efficiently than before). Alternatively we may say that if the circuits are long enough, the mean voltage in a loaded circuit with the same applied E.M.F. is greater than in an unloaded one, and any want of equality in the constants of the A and B lines will result in a greater difference of potential between them, resulting in greater overhearing between the side and phantom circuits, and in cross-talk between the side circuits.

In order to secure a perfect balance, the resistance, capacity, inductance and leakance of the four wires of a phantom circuit must be theoretically equal. It is possible to a large extent to control the equality of the conductor resistance of the cable in the factory. The inductance and effective resistance of the loading coils in a coil-loaded cable can also be very closely balanced. In the loading coils used by the Post Office and manufactured by the Western Electric Co. a variation of not more than 0·25 per cent between the inductance of the two halves of the same loading coil and not more than 0·1 ohm between the direct-current resistance of the two halves of the same coil is guaranteed. A variation of not more than 2 per cent in the inductance of different coils is required and is possible. The leakance of the cable can also be efficiently controlled in manufacture, supplemented by care in laying the cable, and it does not cause appreciable difficulty. The electrostatic capacity of each wire in a four-wire core of the cable cannot, however, be sufficiently equalized in an economical manner in the factory to produce phantom circuits which do not give rise to serious overhearing between side and phantom-loaded circuits in the same four-wire core (or four wires making up the phantom circuit). Special steps are therefore taken to equalize the capacity of the wires in each four-wire group during the process of laying. This is a recognized necessity in all countries where loaded phantom cable circuits are used.*

The steps taken result in reducing the cross-talk between the side circuits, as well as making it possible to use the phantom circuits. It may be noted that

* For proof see Chapter XII of "Telephonic Transmission," by J. G. Hill. (Longmans, Green & Co.)

* S. A. Pollock: *Journal of the Institution of Post Office Electrical Engineers* (April 1914 and January 1915). Under his personal direction the present British system of cable-capacity balancing has been developed.

E. S. Ritter and A. Morris: "The Capacity and Insulation of Cables," *ibid.*, vol. 12, part 4.

Also Sir W. Noble: "The Long-Distance Telephone System of the United Kingdom," *Journal I.E.E.*, 1921, vol. 59, p. 389.

the necessity for balancing arose primarily owing to overhearing between loaded side and phantom circuits. It was formerly common practice to work unbalanced and loaded cable pairs in cables which did not contain phantom circuits.

As a matter of interest it may be placed on record that the first loaded phantom-circuit experiments in this country were carried out, and the possibility of this type of loading demonstrated, between Liverpool and Manchester in 1908. As specially designed loading coils were not available for the phantom circuit coils, telephone transformer coils were used as a substitute, the equal windings of a separate transformer being used for each of the two side circuits which made up the phantom circuit, i.e. an arrangement equivalent to two separate phantom coils for the phantom circuit at the same geographical point, instead of one in the well-known Western Electric Co.'s design. In 1912 it was further demonstrated in this country that phantom circuits in the type of cable then available when using the best available loading coils, were subject to marked overhearing between the side and phantom circuits; but the difficulties were quickly overcome.

Effect of the Introduction of Telephonic Relays on Overhearing and Cross-talk.

Owing to the introduction of two-wire telephone relay working, a degree of accuracy of capacity balance is now required which was not considered necessary for loaded phantom circuits without relays. The main reason is that the telephone relay augments the speech current in the circuit, and where there are several relays the attenuated current arriving at any given relay station may be augmented to approximately the same amplitude as that originally sent from the office of origin, whereas in a long loaded circuit without relays the current is attenuated progressively and continuously in accordance with the compound interest law. As a consequence the mean disturbing voltage in the circuit is much higher in the case of the relayed than the unrelayed two-wire circuit. Contiguous relay circuits have also a greater transmission efficiency, and transmit disturbances with greater intensity than in the case of unrelayed circuits.

Effect of Four-wire Telephone Relay Working on Cross-talk.

It is well known that in some cases there is at present an advantage in utilizing four wires for one telephone underground loaded and relayed circuit, two wires being used for the sending circuit and two for the receiving circuit. This is largely because such an arrangement makes it possible to utilize a much higher degree of relay amplification and to use smaller gauge conductors than in the two-wire relay circuit, or, alternatively, to obtain a louder speech volume with the same type of conductor than is possible with the two-wire system (see British Patent No. 29 165 of 1913 by A. S. J. Van Kesteren). It is not difficult to foresee that the greater amplification of speech energy results in greater inductive disturbance in contiguous circuits. In such cases four-wire circuits are not usually phantomed at present, but cross-talk in adjacent side circuits may nevertheless arise, particularly at the sending end of the cable and at relay stations, notwithstanding the best possible balancing of capacity. As a consequence it becomes necessary to separate the sending circuits from the receiving circuits. It should be noted that the received currents although they may be of great amplitude are often materially less than the sent currents.

Notes on the Balancing of Capacity in Underground Cables.

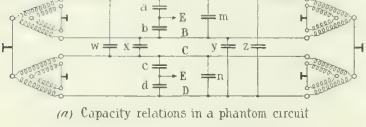
In view of the importance of this problem a considerable amount of attention has been devoted to it in this country. The necessary conditions for producing the required capacity balance have been fully worked out, theoretically and practically. A printed instruction (T.I.XIX Post Office Engineering Department) has been prepared, covering both branches of the subject, and supplied to British manufacturers who undertake the work of supplying the cables and balancing them on the road.

Notwithstanding the complexity of the subject our manufacturers have met all past requirements, and it must be recognized that without their effective and willing co-operation the progress made would not have been possible.

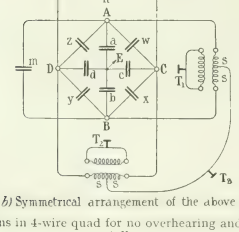
In view of the detailed instruction named it is not necessary to enter into details of the method in question; but the following general remarks may be of interest.

As already mentioned, the form of cable utilized for loaded, phantomed and relayed underground circuits is of the M.T. type and it is usually made up of conductors weighing 20 lb. or 40 lb. per mile per wire. The number of wires varies with the service requirements up to 308 pairs per cable. Each four-wire core in a cable is balanced in short lengths, because if the lengths taken were too long the electrical balance of the constants would not be the same for different frequencies. The complete unit taken for independent balancing is a loading-coil section. The maximum length of a section hitherto adopted in this country is 2·6 miles, but present practice favours 1·6 miles and 1·125 miles. Each loading-coil section is subdivided into lengths of one-tenth of a mile, and these are usually tested separately, and combined with other similar lengths to produce the best result in the loading-coil section. It can be shown that the impedance of a sufficiently short length of cable measured from one end of the cable with the distant end open depends essentially on the capacity and leakance of the length under test, whilst with the circuit closed only the resistance and inductance enter into the measurement. These facts form the basis of the procedure. The leakance, taking into account the high insulation now obtainable, and the inductance of short unloaded lengths of cable are relatively unimportant as factors in causing overhearing in the type of cable considered. (An insulation of 10 000 megohms per mile per wire in air-space paper cable is now obtainable when measured by direct current, but the effective leakance

at 800 periods per second corresponds to only about 1 megohm per mile, wire to wire. The inductance per mile per pair is 1 mH.) The capacity system of a four-wire core may be represented by 10 capacities between different wires and between wires and earth, and it can be shown that from six capacity measurements the necessary combinations to avoid overhearing and cross-talk can be deduced (see Fig. 11). These measurements are made by means of a double bridge specially designed for use on the road. Apparatus is also designed for the rapid measurement of the degree of equality of the resistance of the conductors. Special steps, however, are required in the factory to reduce the out-of-balance of resistance as far as possible, and this is considered much preferable to compensation on the road by crossing. The



(a) Capacity relations in a phantom circuit



(b) Symmetrical arrangement of the above

Conditions in 4-wire quad for no overhearing and no cross-talk.

$p - w - z = 0$ $\quad x = x - y = 0$

$q - z - y = 0$ $\quad u - x - b = 0$

$r - w - x = 0$ $\quad v - c - d = 0$

FIG. 11.

reduction of road balancing of resistance to a minimum is therefore aimed at. Incidentally it may be mentioned that it is highly important that the cable constants, including capacity, should be made as uniform as possible in the factory, in view of the exacting requirements of modern developments and the difficulty in replacing non-uniform cables when faulty. The amount of out-of-balance of capacity and resistance which can be permitted depend essentially on the relation between these quantities and the corresponding amount of cross-talk and overhearing resulting from them; tests of these quantities are therefore necessary. The cross-talk meter is used for this purpose. This instrument, designed by the Western Electric Co. and manufactured in this country by the Cambridge and Paul Instrument Co., is a distortionless artificial cable, the readings being expressed in terms of millionths of the current entering the cross-talk meter, instead of the more usual arrangement of reading in miles of standard cable. It is, however, easy to convert from the one set of readings to the other.*

The instrument is arranged to have a constant sending-end impedance of approximately 666 ohms, no matter what equivalent attenuation length is in circuit; this impedance is generally not the same as the section of cable under test, and this complicates to some extent the interpretation of the results. The comparative overhearing test is made by means of telephones of standard type, by speaking on the circuit giving rise to the interruption (say a side circuit) which is closed by a resistance equal to the characteristic impedance, and listening on the disturbed circuit (say a phantom circuit). The degree of intensity of the sound is observed in the receiver and the telephones are then switched over to the cross-talk meter, which is altered until a sound of the same intensity is heard in the receiver as before. The number of millionths recorded on the dial of the cross-talk meter then indicates the magnitude of the overhearing.

The relation between the capacity measurements and the observed cross-talk is such that if the following values are not exceeded the result is usually satisfactory (see Fig. 11):

$$\begin{aligned} 2(p + q) + u &= 110\ \mu\mu\text{F} \\ 2(r + s) + v &= 110\ \ ,, \\ (p - q) &= 80\ \ ,, \\ u &= 200\ \ ,, \\ v &= 200\ \ ,, \end{aligned}$$

This, however, assumes a uniform distribution of capacity unbalance. In abnormal cases these figures may not correspond closely enough to the mean overhearing and cross-talk observed in normal cases. The overhearing and cross-talk must, however, at present always be taken as the ultimate criteria, inasmuch as they indicate the necessary commercial requirements.

As regards resistance unbalance there is no fixed rule, but experience shows that the difference in resistance of the a and b wires expressed as a percentage of the loop resistance does not usually exceed a mean value of 0·05. The question of capacity balancing has received considerable attention in America and Germany. As regards the former see British Patents Nos. 2 009 and 2 508 of 1913, granted to the Western Electric Co.

Messrs. Siemens and Halske, Berlin, have patented a process for balancing capacity in cables by the addition of small condensers to the cable conductors at suitable distances (British Patent No. 147 013). The condensers employed are made of rolled paper, inserted and sealed in glass tubes, and joined in the cables at loading points. They may be enclosed in separate iron boxes or in loading-coil pots. It is claimed that the device is very successful.†

Professor F. Breisig has treated mathematically the

* See J. G. HILL: "Telephonic Transmission," p. 257.

† A. ERLING: "Fernkabel und Verstärkung," *Elektrotechnische Zeitschrift*, 1921, vol. 42, p. 873.

problem of overhearing and cross-talk in phantom circuits.* He arrives at the conclusion that the overhearing in short lengths of uniform cable such as loading-coil sections with the receiving end insulated, is essentially due to capacity unbalance, and that speech tests may accurately determine its magnitude if a suitably designed artificial cable is used. Details of such an artificial cable are given. The main feature of the artificial cable is that it is constructed of condensers so as to vary in impedance with frequency in the same way as the actual cable under test, and that its impedance is different from its two ends so as to be the same as that of the circuits under test. One end, for example, may be made the same as the phantom circuit, and the other the same as the side circuit.†

Continuously Loaded Cables. Difficulties in Balancing.

When continuously loaded cables require balancing the process is much more complex than in the case of coil-loaded cables, owing to the fact that the inductance added by the iron wire also requires balancing. This subject is at present receiving special study in the British Post Office.

Effects of the Non-uniformity of the Line Constants of a Loaded Telephone Circuit on Telephone Relay Working in the Same Circuit.

The difficulty which we are about to consider arises from the circuit arrangement which it has been found advantageous to adopt for telephonic relay working in both side and phantom circuits. It should be explained that when relays were first used in telephone circuits at intermediate points the relayed voice current was applied to the circuit in bridge, through the differential windings of a transformer, one half of the windings being connected to the "up" line and the other half to the "down" line. Under these conditions if the "up" and "down" lines are not of equal impedance the electrical action in the relay windings is not differential and the amplifier is actuated, and sends a further current to line. As a result of this continued action and reaction the amplifier may give out a loud note. This difficulty may to some extent be minimized by reducing the sensitiveness of the relay, but the amplification of speech is not then so great as it would otherwise be, or, alternatively, if the sensitiveness is not reduced the arrangement is unstable. Further, if the out-of-balance currents sent into the relay are not sufficient to cause howling they may interfere with the clearness of the amplified speech. If more than one relay is introduced into a circuit the difficulties are increased. In order to overcome these difficulties double-relay working was introduced, i.e. the "up" and "down" lines were divided and a separate relay allotted to each, the line in each case being balanced by an artificial network.

In order that the voice currents through the differential windings of the transformer may be equal a complex problem requires solution. It will be remembered that the voice includes a large range of tones of different frequencies, varying from, say, 100 to more than 2 000 periods per second. All these tones are simultaneously impressed on the circuit, and the artificial networks which balance the up and the down lines must be constructed to produce differential action through the transformer windings with all these frequencies simultaneously operating. Now, the characteristic impedance of the line is generally different for every frequency. The characteristic impedance of a uniform unloaded line is given by formula (6). In the case of a uniformly series-loaded line with the terminal loading coils spaced at a distance of one-half a loading-coil section from the ends of the line, the characteristic impedance Z_{01} is given by the following formula:

$$Z_{01} = Z_0 \sqrt{\frac{2Z_0 \sinh \theta + Za\,(\cosh \theta + 1)}{2Z_0 \sinh \theta + Za\,(\cosh \theta - 1)}}\,; \quad (12)$$

where θ is the line angle between two loading coils, Z_0 is the characteristic impedance of the unloaded line, and Za the impedance of the loading coil. In both cases calculation from these formulæ shows that the characteristic impedance changes with frequency in a smooth, regular way. Notwithstanding the complexity of the physical problem involved in balancing the multiple frequencies of the voice in unloaded or loaded lines, a comparatively simple balancing network can be designed which involves capacity, inductance, and resistance, and which effectively balances the differential transformer and circuit previously referred to if the conditions of formulæ (6) and (12) are fulfilled. The network is constructed to balance the circuit for a range of frequencies between 300 and 2 000 periods per second. Filters are necessary to cut out frequencies outside the range for which the circuit is balanced. The result of the application of these devices is that the repeaters used in double-wire working are stable and give good articulation of speech. Detailed examples of the design of balancing networks have been given.*

In the case of unloaded, uniform cable lines the line impedance which requires balancing may be taken to be that calculated from formula (6). This involves constructing a network for the given circuit through the range of frequencies first specified. The calculated impedance in this case usually approximates with sufficient accuracy to the measured impedance of that circuit, through the same range of frequencies dealt with. If, however, the circuit is series-loaded the values calculated may differ appreciably from the measured impedances. Fig. 12 shows a calculated impedance curve of a loaded circuit in dotted lines, and the result of the measured impedance over the same frequency range is given in solid lines. The difference is due to the want of uniformity of the

* "Über das Nebensprechen In Fernsprechkreisen," *Electrotechnische Zeitschrift*, 1921, vol. 42, p. 933.

† L. Lichtenstein: "Über das Nebensprechen in Kombinierten Fernsprechämtern," *E.T.Z.*, 1920, 4 and 11 March.

* C. Robinson and R. M. Chamney: "Gas Discharge Telephone Relays and their Application to Commercial Circuits," *Professional Papers of the Institution of Post Office Electrical Engineers*, No. 76.

circuit constants. Formula 12 is based on the supposed uniform distribution of the capacity, leakance and resistance throughout the circuit, and also supposes equal inductance and equal spacing of the loading coils. Where these conditions are departed from, notably as regards uniformity of spacing and variation in inductance and capacity, reflection takes place at points of non-uniformity, and the effect varies with frequency. The result of these variations is shown in Fig. 12. Previous to the introduction of relay working this phenomenon had comparatively little importance, and it may be mentioned that the circuit which is here taken as an example and illustrated in Fig. 12 was designed for pre-relay conditions, but such a circuit is not sufficiently uniform to give the results required in highly efficient relay working. It now becomes necessary to specify limits to the permissible variation of (*a*) the spacing distance of the loading coils, (*b*) the inductance of any coil from the mean value of inductance per coil, (*c*) the capacity of any

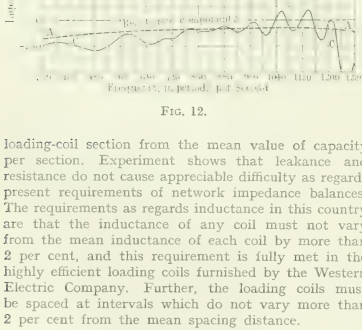

Impedance of loaded underground
Curve A. Calculated characteristic impedance
Curve C. Projected impedance
Frequency in period per second

FIG. 12.

loading-coil section from the mean value of capacity per section. Experiment shows that leakance and resistance do not cause appreciable difficulty as regards present requirements of network impedance balances. The requirements as regards inductance in this country are that the inductance of any coil must not vary from the mean inductance of each coil by more than 2 per cent, and this requirement is fully met in the highly efficient loading coils furnished by the Western Electric Company. Further, the loading coils must be spaced at intervals which do not vary more than 2 per cent from the mean spacing distance.

As regards capacity, a restriction of the amount of non-uniformity permissible has not yet been fixed in this country, but experiments made in Great Britain point to the necessity of some limitation, of the same order of accuracy as in the case of the inductance. Recent extensive experiments made in Germany on the influence of inequalities in the construction of coil-loaded telephone cables on their characteristic impedance by K. W. Wagner and K. Küpfmüller * point to the fact that the inductance per section should not vary more than 2 per cent from the mean inductance per section, and that the electrostatic capacity per section should not vary more than $1\frac{1}{2}$ per cent from the mean capacity per section. The same general problem has also received careful attention in America.

When the limitations of capacity, inductance and spacing here outlined are observed, the variations from the calculated curves—such for example as shown by Fig. 12—are materially reduced, the amplitude of the sinuous curve being reduced to negligible proportions.

Before concluding it should be stated that it has not been overlooked that a system of high-frequency telegraphy and telephony has recently been developed in America, largely due to the labours of Major-General G. O. Squier, and also the Western Electric Co. in co-operation with the American Telephone and Telegraph Co. It would have been impossible, however, in any case to deal properly with the subject in the limits of this paper. High-frequency circuits are at present regarded, moreover, as supplementing, but not supplanting, the methods here described. The subject is dealt with in Major-General Squier's publications and has also been treated by E. H. Colpitts and O. B. Blackwell.*

The study of superposed circuits, used in the widest sense, is one of increasing importance. It is not one for the application of cut-and-dried rules. The problems dealt with are so complex as to require special study of each case in all its aspects. The progress which has been made in recent years has resulted in the replacing, to some extent, of heavy-gauge overhead wires of limited electrical stability and carrying capacity, by small loaded and relayed underground circuits of uniform stability and efficiency. It must not be hastily assumed, however, that the reduction in cost is at all proportionate to the decrease in the weight of copper per mile. The cost of loading such cables is considerable, and to this must be added the cost of providing and maintaining relay stations, with the necessary equipment and staff. It may be stated as a broad proposition that a loaded circuit of a given transmission efficiency may be provided by a relatively large quantity of copper and a relatively small quantity of loading coils, or, conversely, within known limits, by a less quantity of copper and more loading coils. The engineering problem consists in providing the required efficiency at the cheapest cost. Similarly with relay stations; the more of these we provide the less the amount of copper and coils which it is necessary to put into the loaded circuits for a given overall transmission efficiency, and vice versa; but there is a point beyond which it is cheaper to provide loaded conductors than relay stations. The ultimate object is to find that combination which for a given number of years gives the required overall efficiency at the most economical cost. This is merely one example of many problems which require solution.

The design and calculation of such a system involves engineering problems of great complexity, as may be

* *Archiv für Elektrotechnik*, 1921, vol. 9, p. 461.

* "Carrier Current Telephony and Telegraphy," *Journal of the American I.E.E.*, 1921, vol. 40, p. 310. See also "Multiplex Telegraphy and Telephony," by K. W. WAGNER, *Elektrotechnische Zeitschrift*, 1919, vol. 40.

seen from the details given in the paper. The ultimate result, however, should be a system of greater efficiency and stability than any provided in the past.

The author is obliged to Mr. A. Morris for reading the proofs and for suggestions.

APPENDIX.

Electrical Filters.

In some cases, more particularly when relatively high speech-magnification is utilized, the higher unbalanced frequencies which are not dealt with in the impedance balancing network are liable to set up oscillations in telephone repeaters, and electric filters may be employed to cut off all frequencies above the range which experiment shows may be dispensed with without appreciable distortion of speech.

The method of calculation used for filters may also be utilized to calculate impedances for use at the end of composited circuits.

Filters are also of considerable importance in connection with high-frequency guided telephony and telegraphy. It may therefore be of use to outline a relatively simple method of arriving at the fundamental data of these devices, more especially as the method is applicable to artificial circuits generally. The properties of such circuits are well known, and the object of the following notes is to show a method of obtaining from known data the principal details for the calculation of filters by inspection of tabulated formulæ.

The principal formulæ for the calculation of the transmission characteristics of electrical filters may be written down by inspection of the known impedance of the three branches which make up an artificial T circuit, on the assumption that a source of sine-wave E.M.F. in the steady state is transmitted by the filter circuits. It will simplify the matter to recall the principal properties of such circuits, and they are as follows :—

If an artificial circuit is made up of any three independent impedances Z_1 and Z_2 arranged as in Fig. 13(*a*) where the two equal branches Z_2 form the arms of the arrangement, with the middle point earthed through an impedance Z_1 we have one section of the proposed artificial circuit. Suppose this section to attenuate the voltage and current transmitted through it. If now the number of equal sections be indefinitely increased and joined in series, the impedance of the combination as measured from the sending end A will become constant, whether the distant end is opened or closed. This impedance will be called the characteristic impedance and will be represented by the symbol Z_0. If now a single impedance be constructed having the value Z_0, and if this impedance be used to close one section or to close any number of sections, the impedance as measured from A will always be Z_0 in the same conditions of test. So long as the preceding conditions are fulfilled the ratio between the current I_1 at the beginning of any section and the current I_2 leaving the same section or any number n of sections will always be $I_2/I_1 = e^{-n\theta}$, where e is the base of the natural logarithms and θ is the equivalent propagation constant of the artificial section. Further, θ is a vector quantity such that

$$\theta = \alpha + \beta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 13)$$

where α represents the retardation of the wave per section, and β the real part of the attenuation constant. If, instead of closing the circuit through an

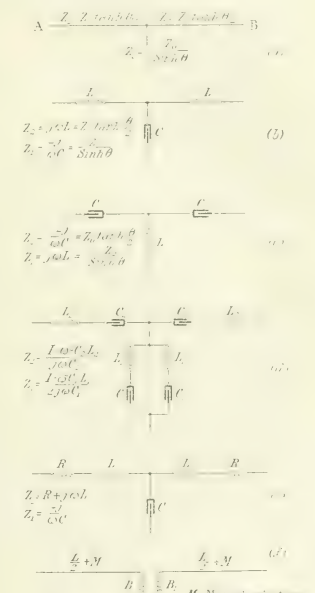


Fig. 13.

impedance, one section be taken and earthed at the receiving end we have the relation

$$I_1/I_2 = \cosh\theta \quad . \quad . \quad . \quad . \quad . \quad . \quad 14)$$

Now to determine the transmission properties of filters we require to know the quantities just defined, namely, Z_0, θ, and $\cosh\theta$, as will be shown later by an example. These quantities may be written down directly in terms of Z_1 and Z_2 if these independent

impedances are arranged in an artificial circuit as in Fig. 13(*a*) and have the following values assigned to them:

$$Z_1 = \frac{Z_0}{\sinh\theta} \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

$$Z_2 = Z_0 \tanh\tfrac{1}{2}\theta \quad . \quad . \quad . \quad . \quad . \quad (16)$$

All the preceding formulæ are proved in text-books on telephonic transmission.

To find Z_0 in terms of Z_1 and Z_2, by inspection of equations (15) and (16) we have

$$Z_0^2 + 2Z_2 \times Z_1 = Z_0^2\tanh^2\tfrac{1}{2}\theta + 2Z_0\tanh\tfrac{1}{2}\theta \times Z_0\sinh\theta = Z_0^2\left[\frac{(\cosh\theta-1)^2}{\sinh^2\theta} + \frac{2(\cosh\theta-1)}{\sinh^2\theta}\right] = Z_0^2;$$

whence

$$Z_0 = \sqrt{(Z_2^2 + 2Z_1Z_2)} \quad . \quad . \quad . \quad . \quad (17)$$

Now

$$e^\theta = \sinh\theta + \cosh\theta$$

By inspection of (15)

$$Z_0/Z_1 = \sinh\theta \quad . \quad . \quad . \quad . \quad . \quad (18)$$

To find $\cosh\theta$, we have

$$Z_2/Z_1 = Z_0\tanh\tfrac{1}{2}\theta \div \sinh\theta/Z_0 = \frac{\cosh\theta-1}{\sinh\theta} \times \sinh\theta = \cosh\theta - 1;$$

whence

$$\frac{Z_2}{Z_1} + 1 = \cosh\theta \quad . \quad . \quad . \quad . \quad (19)$$

$$\therefore\ e^\theta = \sinh\theta + \cosh\theta = \frac{Z_0}{Z_1} + \left(\frac{Z_2}{Z_1}+1\right) \quad . \quad (20)$$

The real part β of the complex attenuation constant θ is

$$\beta = \log_e \mathrm{mod}\left[\left(\frac{Z_2}{Z_1}+1\right) + \frac{Z_0}{Z_1}\right] \quad . \quad . \quad (21)$$

i.e. the logarithm of the modulus of the quantity in the brackets in (21).

As an example of the application of these formulæ consider the simple case depicted in Fig. 13(*b*), which is a filter with negligible resistance.

We have by inspection of (15) to (20) and Fig. 13(*b*)

$$\cosh\theta = \frac{Z_2}{Z_1} + 1 = \frac{j\omega L}{-jI(\omega C)} + 1 = 1 - \omega^2CL$$

$$Z_0^2 = Z_2^2 + 2Z_1Z_2 = -\omega^2L^2 + 2L/C$$

$$\therefore\ Z_0 = \sqrt{\left(\frac{L}{C}\right)}\sqrt{(2 - \omega^2CL)}$$

$$e^\theta = \cosh\theta + \sinh\theta = 1 - \omega^2CL + Z_0/Z_1$$

$$= 1 - \omega^2CL + \sqrt{\left(\frac{L}{C}\right)}\sqrt{(2-\omega^2CL)} \times -jI\omega c$$

$$= 1 - \omega^2CL + j\omega\sqrt{(CL)}\sqrt{(2-\omega^2CL)}$$

β = log$_e$ of the modulus of this quantity.

α is the angle in radians per filter section such that $e^\theta = e^{j}\angle\alpha$.

Examination of these equations shows that for all values of ω^2CL up to 2 such a filter transmits without attenuation. The retardation α per section in the same range increases from 0 to π. Above $\omega^2CL = 2$ there is attenuation which increases rapidly with frequency, but the retardation per section during this range remains constant with the value π.

Taking the following values for illustration, if

$$C = 2{\cdot}2\ \mu\mathrm{F} \text{ and } L = 10 \text{ henrys}$$

Then when $\omega = 300$, $\beta = 0$, $\alpha = \pi$

$\omega = 600$, $\beta = 2{\cdot}634$, $\alpha = \pi$

Z_0 decreases with frequency, becoming zero when $\omega^2CL = 2$.

For values of ω^2CL greater than 2, Z_0 is imaginary. Such a filter passes all frequencies below 48 per second without attenuation.

The same method may be followed in more complex cases.

Electrical Filters with Mutual Inductance.

Suppose as a simple case of such a filter that we have a continuous resistanceless inductive coil connected as shown in Fig. 13(*f*), the middle of the coil being connected to earth through a condenser; there will then be mutual inductance between the arms of the T. If Z_2 is used as a general symbol for the impedance of each of the horizontal branches of a T circuit, and Z_1 is the impedance of the vertical branch of the same circuit, excluding in each case the portion due to the mutual inductance M, it can be shown * that

$$\frac{I_1}{I_2} = \cosh\theta = \frac{Z_2 + Z_1}{Z_1 - j\omega M} \quad . \quad . \quad . \quad (22)$$

$$Z_0 = \sqrt{[(Z_2 + Z_1)^2 - (Z_1 - j\omega M)^2]} \quad . \quad (23)$$

It can further be shown that the results given in (22) and (23) are identical with those obtained from a simple T circuit in which the independent value Z_2—as in Fig. 13(*a*)—is replaced by $Z_2 + j\omega M = Z_{2M}$ (say) in each horizontal arm of the T circuit, whilst at the same time Z_1 is replaced by the quantity $Z_1 - j\omega M = Z_{1M}$. The impedances Z_1 and Z_2 may be complex vectors. The mutual inductance may be positive or negative and have any desired coupling. The + sign is used for convenience. Now the total impedance of the supposed resistanceless coil, which has a self-induction L and a mutual inductance $2M$, is $j\omega L + 2j\omega M$, and Fig. 13(*f*) gives the fundamental data for the calculation of the transmission constants of such a coil when used as a filter. Applying the preceding data we have $Z_2 = j\omega\tfrac{1}{2}L$, $Z_1 = -jI(\omega C)$. In order to deduce the value of cosh θ by means of a simple T circuit we proceed as follows:

By analogy with Fig. 13(*a*) and formula (19) we have

$$\cosh\theta = \frac{Z_{2M}}{Z_{1M}} + 1 = \frac{Z_2 + j\omega M}{Z_1 - j\omega M} + 1 = \frac{Z_2}{Z_1} + \frac{j\omega M}{Z_1 - j\omega M}$$

$$= \frac{j\omega\left(\frac{L}{2} + M\right)}{-jI(\omega C) - \omega M} + 1 = \frac{\omega^2CL - 2}{-2(\omega^2CM + 1)}$$

Proceeding in this way the following formulæ and any other similar formulæ may be developed:—

$$Z_0^2 = Z_{2M}^2 + 2Z_{1M}Z_{2M} \quad [\text{see formula (17)}]$$

* G. W. Pierce: "Electric Oscillations," chap. xvi. (McGraw Hill Book Co.)

that is $Z_0^2 = Z_2 + j\omega M + 2(Z_2 + j\omega M)(Z_1 - j\omega M)$
$= (Z_2 + Z_1)^2 - (Z_1 - j\omega M)^2$
$\therefore Z_0 = \sqrt{[(Z_2 + Z_1)^2 - (Z_1 - j\omega M)^2]}$
[see formula (23)]

$$\sinh\theta = \frac{Z_0}{Z_{1M}} = \frac{\sqrt{[(Z_2 + Z_1)^2 - (Z_1 - j\omega M)^2]}}{Z_1 - j\omega M} \quad (24)$$

[see formula (18)]

If $j\omega M = 0$ formulæ (22) to (24) reduce to formulæ (17) to (19).

Special case.

If $Z_1 = Z_2$ or $Z_{1M} = Z_{2M}$ then $Z_1/Z_2 = 1$ and, by (19), $\cosh\theta$ is constant for all frequencies, since $Z_2/Z_1 = 1$.

From the detailed study of the formulæ given, the electrical constants necessary for various forms of filters may be deduced.

The effect of apparatus joined to the ends of such filters follows the usual known transmission laws applicable to equivalent T circuits.

To Determine the Range of Frequency in which a Filter has No Attenuation, and the Corresponding Angle of Retardation per Filter Section.

Since $\theta = j\alpha + \beta$ by (13) we may write

$$e^{(j\alpha+\beta)} = \cosh(j\alpha + \beta) + \sinh(j\alpha + \beta)$$
$$= (\cosh\beta\cos\alpha + j\sinh\beta\sin\alpha) + (\sinh\beta\cos\alpha + j\cosh\beta\sin\alpha) \quad . \quad (25)$$

when $\cosh\beta = 1$, $\sinh\beta = 0$, and $\beta = 0$, (25) then becomes

$$e^{j\alpha} = \cos\alpha + j\sin\alpha \quad . \quad . \quad . \quad . \quad . \quad (26)$$

For the case of no attenuation we have therefore by (20)

$$\left(\frac{Z_2}{Z_1} - 1\right) \div \left(\frac{Z_0}{Z_1}\right) = \cos\alpha - j\sin\alpha \quad . \quad (27)$$

when $R = 0$, $\frac{Z_2}{Z_1}$ is real and we have

$$\frac{Z_2}{Z_1} \div 1 = \cos\alpha \quad . \quad . \quad . \quad . \quad . \quad (28)$$

$$\frac{Z_0}{Z_1} = j\sin\alpha \quad . \quad . \quad . \quad . \quad . \quad (29)$$

The angle of retardation α associated with any frequency in the range of frequency obtained when $\beta = 0$ may be found from (27). Equation (28) has + 1 and − 1 as limits, and the cut-off frequencies may be determined from these limits.

Examples.

Case of Fig. 13 (*b*).

Cut-off limits.

(*a*) $\frac{Z_2}{Z_1} + 1 = 1 - \omega^2 CL = 1,$

or $-\omega^2 CL = 0$ and $\underline{\omega = 0}$

(*b*) $1 - \omega^2 CL = -1$, or $\omega^2 CL = 2$ and $\underline{\omega = \sqrt{\left(\frac{2}{CL}\right)}}$

i.e. there is no attenuation for frequencies between the cut-off limits having the values ω in (*a*) and (*b*).

Case of Fig. 13 (*c*).

Cut-off limits

(*a*) $\frac{Z_2}{Z_1} - 1 = 1 - \frac{1}{\omega^2 CL} - 1,$

or $-\frac{1}{\omega^2 CL} = 0$ and $\underline{\omega = \infty}$

(*b*) $1 - \frac{1}{\omega^2 CL} = -1$, or $\frac{1}{\omega^2 CL} = 2$ and $\underline{\omega = \frac{1}{\sqrt{(2CL)}}}$

Case of Fig. 13 (*f*).

(*a*) $\frac{Z_{2M}}{Z_{1M}} \div 1 = \frac{Z_2 - j\omega M}{Z_1 - j\omega M} \div 1 = \frac{\omega^2 CL - 2}{-2(\omega^2 CM + 1)} = 1$

or $\omega^2 C(L + 2M) = 0$

This is indeterminate; there is no lower frequency limit, and $\underline{\omega = 0}$.

(*b*) $\frac{\omega^2 CL - 2}{-2(\omega^2 CM + 1)} = -1$, and $\omega = \underline{\sqrt{\frac{2}{C(L - 2M)}}}$

In the case of (*a*) in each instance $\alpha = 0$.
In the case of (*b*) in each instance $\alpha = \pi$.

Discussion at The Institution, 16 March, 1922.

Sir Andrew Ogilvie: This paper is of a very technical character, and perhaps I ought to apologize for offering a few remarks on the historical and commercial aspects of the systems, while leaving the technical aspects to be dealt with by those who are more fitted to speak on them. I remember the enthusiasm in telegraph circles which followed the Van Rysselberghe invention. At that time the telegraph industry was beginning to apprehend the competition which would arise from telephones, and this seemed a method of salvation by means of which those who owned telegraph systems might get a cheap share in the new business. Those hopes were not fulfilled. Manifestly the Van Rysselberghe system is not one which lends itself to ordinary exchange working, and the general conditions of trunk or long-distance working in those days, as well as the special limitations of the Van Rysselberghe system, gave it only a very limited range of usefulness for long-distance work. I suppose that its chief use has been for railway purposes, but in a certain number of cases at the beginning of the present century, when the Post Office first undertook the extension of the telephone system in rural districts, the system was used for converting small village telegraph offices to telephone working, thereby enabling them to be linked up to the telephone system of the country. During the war the Fullerphone development of the method was very useful for military purposes, not as a specially good means of communication, but because it was secret and could not be overheard on enemy listening sets. The simplex

and composited methods, described on page 679, of superposing telegraph circuits on telephone circuits, have not been very largely used in this country. The obvious reason is that those methods are useful only to administrations which have both telephone and telegraph business. The National Telephone Company had a considerable number of trunk circuits before 1896 when their lines were taken over by the Post Office, but they were not licensed for telegraph business, and therefore they had no business which required combined working. The Post Office, on the other hand, in 1896 took over the whole of the trunk telephone lines, but had already in existence a very large telegraph system which had been developed to meet a traffic that was at its maximum somewhere about 1890, and therefore there was no need for the Post Office to use this system for its telegraph business. If this had been a new country, and the telegraph and telephone business had had to be provided for as a new thing, obviously the proper way of doing it would have been to provide telephone circuits, and to have done all the telegraph business with simplex and composited telegraph circuits on the telephone circuits. As the author states, a very large business was developed by the American Telephone and Telegraph Company in leasing out composited telegraph circuits on their long-distance telephone lines to newspapers and Press agencies, to Stock Exchange and to other business firms having establishments in a number of big centres. A great many ingenious applications of the system have been developed in that country. When the trunk telephone traffic in this country grew very largely we did use the system in the Post Office for providing "call-wire" circuits for telephone purposes. If there is a large group of trunk lines between two places, such as London and Manchester, the most efficient method of working is to have service communications passed over one channel and to use the other lines entirely for the connections between subscribers. The use of a composited telegraph circuit superposed on one of these trunk lines provided for the service communications and enabled the whole number of any group of long-distance circuits to be used for purely telephone purposes. It was economical in many cases to set against the revenue obtained from the telephone line thus set free the expenses involved in employing special telegraphists for the superposed circuit. Also a very useful purpose has been served by circuits of this kind which have been superposed on telephone circuits between London and Paris for public telegraph business, and in this way a good deal of telegraph work has been done at a very small cost. The superposition of phantom telephone circuits on telephone circuits is, however, a matter of much more general utility and importance. The Post Office has been very successful in superposing phantom circuits on submarine cable wires, and I believe it was in the Post Office that the methods were first developed which enabled four telephone circuits, two phantom and two physical, to be worked on a four-wire submarine cable. The great importance of the phantoming system at the present time comes from the extraordinary development that is taking place in long-distance telephone communication owing to the use of thermionic valve relays on loaded cables. The notable investigations which the Western Electric Company has carried out recently and put into the shape of practical equipment, about which Mr. Gill could give us a great deal of interesting information, has opened an entirely new field for long-distance communication. It is now physically possible for communication to take place between any one part of Europe and another by means of circuits composed of 40-lb. conductors. The number of physical circuits of this size which can be got into a cable, increased by the number of phantom circuits which can be superposed, will make it commercially possible to provide international communication on a scale hitherto undreamed of, and it is the great importance of this aspect of the matter which makes it necessary to re-examine the subject and makes this paper so interesting. If it is possible to provide on the same cables superposed telegraph circuits as well as phantom circuits by means of the methods described the service will be still further increased, and we shall get to a stage in international electrical communications for which in the past we never ventured to hope.

Mr. A. B. Hart: The author gives on page 677 a curve showing the rise of current in a composited circuit. I venture to suggest that that curve does not really represent the condition of things as we ought to recognize it to-day. It shows a current rising very smoothly from zero to a maximum value. The reasons for which I challenge that curve are very practical ones, and I will give them very briefly. In connection with some recent experiments on a composited circuit we experienced very great interference in the telephone circuit from the telegraph signals. The telegraphs were being worked at a comparatively low speed. The telephone was composited or superposed on the wires. The point of my remark is that the couplings between the telephone circuit and the telegraphs were two very tiny condensers. Those condensers would offer an infinite impedance to the d.c. telegraph current, or, if we look at the telegraph as working at a slow, alternating current they would still offer a very high impedance. Yet at the beginning of those experiments we suffered very great interference from the telephone. We overcame it to a certain extent, but we came away from that experiment feeling that there was something wrong with curves of this kind, and that what we were really dealing with was a rise of current of an oscillatory character. I should like to know the author's opinion as to whether this is really not an oscillatory current. It has to be realized that the rocking lever of the Wheatstone transmitter when it is at work is a stiff piece of mechanism, and when it does strike it bounces, and that produces a vibration; but the important thing is the electrical oscillation that follows. That leads me to the point that it is necessary in composited circuits to know what is the minimum frequency which must be transmitted in order to give satisfactory telegraph working, and then to cut off the unnecessary frequencies by means of filters. The second point on which I venture to criticize the author is that in two places the statement is made that the phantom circuit, the 4-wire core, has a higher transmission efficiency, usually to the extent of 15 to

25 per cent. owing to the relatively smaller capacity of the phantom circuit and its higher degree of loading. That statement, which is on page 684, I have read several times and have tried to paraphrase. Let us assume that the cable has a 40-lb. conductor; the amount of copper in the phantom combination will therefore be four times 40, i.e. 160 lb. Now let us consider an equivalent physical circuit which will have two conductors, each of 80 lb. a mile, and load that physical circuit with the same loading coil as that which is used with the phantom on the 40-lb. circuit. The efficiency of that 80-lb. physical circuit will be considerably greater than the physical 40-lb. circuit, but not because its capacity is smaller. The capacity will be about the same; but it has only one-half the resistance of the 40-lb. circuit. How then can it be correct to say that the 40-lb. phantom is better than the 40-lb. physical circuit owing to the relatively smaller capacity of the phantom, when as a matter of fact the phantom has a 50 per cent greater capacity? Then the author makes a statement on page 683 with regard to the transformer used in phantom circuits. He refers to its high efficiency, which I do not question, and mentions that the method of winding to secure the differential action is one devised by the Post Office. I think a word of warning is necessary here. That transformer was designed for efficiency and it gets its efficiency mainly because of the way in which it is wound. The primary and the secondary are wound one over the other all the way round the coil, but the efficiency of the transformer is very largely due to the high capacity between the primary and the secondary. It is a fact, that it will not introduce unbalance into a well-balanced circuit in which it is put, but, especially in connection with telegraph superposing, we frequently have to couple an unbalanced circuit to a balanced circuit. The very high efficiency of this coil is thus rather a disadvantage, in that it tends to transmit an "unbalance" to a balanced circuit. It is better in these cases to sacrifice a little transmission efficiency in order to lose the disadvantage of carrying over a disturbance on an unbalanced circuit to a balanced circuit. The author mentions that the loading coils must be spaced at intervals which do not vary more than 2 per cent of the main distance, which means that we are actually working to 30 feet. An accurate spacing is worth getting because there is no expense attached to it. It is simply a matter of care.

Mr. A. E. Thompson: Of the two methods of superposing discussed, the composite has important advantages from the standpoint of economy in line plant. It enables two separate telegraph circuits to be derived from one telephone pair without in any way interfering with the use of the physical circuit for phantom purposes. The simplex method permits only one telegraph circuit to be derived from one telephone pair, and this at the expense of the valuable phantom facility. It is interesting to note that composited circuits have been used in this country for many years, but it is probable that the number is not a large one and is insignificant compared with the number of simplexed circuits. The same appears to be the case in other European countries, but signs are not wanting that the composite will have its vogue in the near future. The Danish Administration composited a number of their circuits about a year ago and are well satisfied with the service obtained. They consider the arrangement to be superior to the simplex, and it is stated that they are intending to introduce it more and more, and to a large extent will stop erecting lines for telegraph purposes only. The French also are trying out the method. The author states on page 683 that, so far as he is aware, combined phantom circuit and composite working has not been used in Europe. I am informed, however, that the Danish Administration are using this arrangement over the following phantomed circuits: Copenhagen–Aarhus; Copenhagen–Aalborg; Copenhagen–Odense; Copenhagen–Nykoping, Falster; Copenhagen–Hamburg. On the Hamburg circuit the American composite method is used at Copenhagen, the Germans using their own apparatus at the distant end. Three of the derived telegraph circuits are used as order wires for the three telephone circuits, and the fourth for general telegraph service. In France the American Army used this

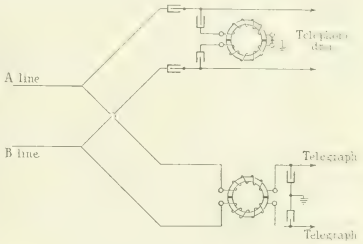


FIG. A.—Terminal composite set.

combined method of working also. The first combined phantom and composite circuit used by the American Army was installed in June 1918, between Tours and Chaumont, with repeaters at Autun, a total distance of 306 miles. This provided 3 telephone and 4 telegraph circuits. Two of the telegraph circuits were equipped with Morse apparatus and two with Western Electric multiplex apparatus, one being a two-channel duplex (speed 40 words per minute per channel) and the other a three-channel duplex. Over the two pairs of wires it was possible, therefore, to transmit 3 telephone messages and 14 telegraph messages. It has been alleged that the composite method of superposing is unsuited for use in this country, on account of bad weather conditions. To determine whether this is the case, an experiment has been made over a trunk circuit between Euston and Rugby (84 miles), by the courtesy of Lieut.-Col. Cortez Leigh. Standard Western Electric composite sets and composite ringers were used. One of the derived telegraph circuits was equipped with double-current duplex apparatus, and the other was used for clearing purposes (see Fig. A). During what are probably the worst months in the year from the standpoint of insulation (November to March) an excellent service was secured,

and there was not a single interruption. The lowest total insulation resistance recorded was 2 000 ohms. It was never possible to detect Morse "thump" in the telephones, and the transmission loss due to the composite apparatus was practically negligible. In America the system has made extraordinary headway. The Bell companies have about 700 000 miles of telegraph circuits in use to-day, of which no less than 90 per cent are secured from composited circuits. These are rented to the Press, stockbrokers and bankers, etc., and the revenue obtained can well be imagined. The composite is in general use by the railways also, and it is stated that single lines for telegraph purposes only are almost a thing of the past. As no mention is made of the American composite method in this paper, a brief outline may be of interest. It is an arrangement of electrical filters which divide the lines into two branches. The high-pass filter in the telephone branch permits frequencies above 100 periods per second only to pass, while the low-pass filter in the telegraph branch suppresses frequencies above 80 periods per second. To secure a balance the two inductances in each filter are wound on the same core and are enclosed in a crosstalk-proof shell. The total transmission loss due to the composite equipment is generally less than one standard mile on non-loaded circuits and may be as low as one-tenth standard mile on loaded circuits. The speed at which the telegraphs may be operated is restricted on account of the suppression of the higher harmonics, the effect being to round off the wave shape of the signals. Over comparatively short distances it is practicable to operate simplex Morse at 40 periods per second, equivalent to 88 words per minute. For duplex working, 30 periods is about the maximum, but it is not usual to exceed 25 periods. At this frequency the 3rd harmonic is permitted to pass, with a consequent improvement in the wave-shape of the signals. The duplex speeds equivalent to 25 periods are as follows:

Wheatstone, 60 words per minute.

Single-channel systems:
Western Electric Start Stop, 70 words per minute.
Morkrum, 70 words per minute.

Multiplex:
Baudot (3 channels), 29 words per minute per channel.
Western Electric (3 channels), 33 words per minute per channel.

To enable the usual switchboard arrangements to be retained for signalling purposes a composite ringer is usually employed in preference to a howler. Presumably, this is the Western Electric device referred to on page 678. It comprises two circuits shunted across the lines at a point between the composite set and the switchboard. One circuit contains a relay responsive to 16-period currents, and the other a relay responsive to 135-period currents. Each relay is arranged to transmit from a local source, current of the other frequency than that by which it has been operated; that is, outgoing 16-period currents from the switchboard cause 135-period currents to be transmitted over the lines, and incoming 135-period currents cause 16-period ringing current to be transmitted to the switchboard.

In comparison with the American method, the Post Office arrangement shown in Fig. 7 appears to me to have the following disadvantages:

(1) The telegraph signals pass through one winding of the repeating coil. This must introduce a certain amount of Morse "thump" in the telephone, but possibly it has been overcome by giving a large capacity to the condensers tapped to earth.
(2) If these condensers are of greater capacity than 6 μF and 2 μF, as used in the American composite, the efficiency of telegraph transmission will be reduced.
(3) The telegraph legs are connected together through condensers. This probably results in a considerable amount of cross-fire or inductive interference, particularly if both legs are used for telegraph service.
(4) No drainage path to earth is provided as a protection against cross-fire between the telegraph circuits.

In conclusion I should like to ask the author if he can tell us how many circuits are equipped with this arrangement and also whether both of the telegraph legs are actually being used for telegraph service.

Mr. S. Inada: The Institution has been of the greatest possible help to electrical engineers in Japan, who take every opportunity of studying the interesting and instructive papers that are read at its meetings. This paper will prove of great value to us in Japan, and will be eagerly studied by those who have read Mr. Byng's recent paper. We have now come to a turning point in "weak current" engineering, and many papers dealing with the subject under discussion have been read before the American Institute and also the Institution. The problem dealt with in the present paper is most interesting. Since last summer I have been making a tour through a great many countries, and I have been very much struck by the great strides being made in all of them with a view to obtaining highly efficient combined circuits for telephone and telegraph purposes. I hope that as a result of this paper a great advance will be made in our knowledge of electrical engineering. I am extremely grateful for the cordial welcome that has been extended to me, and I feel it a very great honour to have had the opportunity of speaking at this Institution.

Mr. W. Aitken: I should like to ask a few questions with regard to the use of the terms employed by the author. For instance, he speaks of "side" circuits. I have always heard them referred to as "physical" circuits, and it seems to me that a physical circuit has much more meaning than a side circuit has. Many rather contradictory terms are creeping into our nomenclature. For instance, to-night we have heard of telephone relays. These are non-circuit-closing, but we have also telephone relays which are circuit-closing. Again, "repeater" has two meanings, a speech repeater (inductive coupling) and an impulse repeater. It would be good to have distinctive terms for those devices. Telephone circuits are now becoming very complicated. As the author has explained, some trunk lines are

loaded, superimposed and fitted with amplifiers. We have also a means of calling over these circuits, and we should like to have supervisory signals automatically controlling them. Before long we shall be considering the question of automatic impulses over the circuits, at any rate within a radius of 100 miles: the Americans already have begun work in that direction. We shall also want to meter over these circuits. It is difficult to forecast what the telephone circuit will be like eventually.

Mr. W. J. Thorrowgood: I do not quite agree with a previous speaker that we have come to the end of should like to say that Fig. B represents a telegraph circuit between Bath and Bournemouth and Highbridge. The distance between Bath and Bournemouth is 76 miles, and there is a spur out from that line near Glastonbury to Highbridge. The distance between Highbridge and Bournemouth is 72 miles. On that single wire there are 14 telegraph instruments and 15 telephone instruments, and it is possible to speak from one end of the line to the other. Probably it would not meet the conditions that are put upon the Post Office, but I think it will show that the possibilities of carrying the Van Rysselberghe system farther

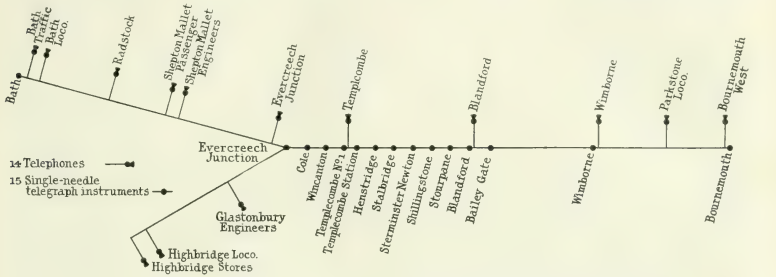


FIG. B.—Telegraph and telephone communication between Bath, Highbridge, and Bournemouth.

the Van Rysselberghe system. The author has dealt with the problem from the Post Office side, but there is another side of the subject which must be considered, namely, what has been termed the railway side. I thought one or two instances of superimposed telegraphs and telephones in railway working would be of interest to members, and for that purpose I have had Figs. B and C prepared. Stress has been laid on the diffi- are by no means small. Fig. C depicts what has been called a composited circuit. There again the apparatus that separates the telegraph from the telephone is very simple indeed. Both these examples have been in use for a large number of years. In this diagram we have practically a bridge circuit; it is a representation of a 79-mile circuit between Waterloo and Southampton. There are 2 telegraph instruments, a single-needle

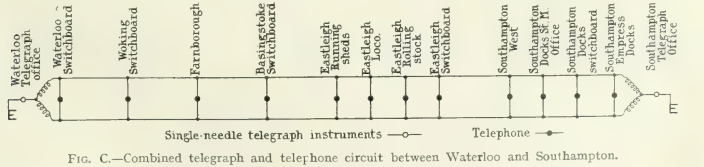


FIG. C.—Combined telegraph and telephone circuit between Waterloo and Southampton.

culties and complications of these circuits. I can only say that those who are interested in the combined telephone and telegraph service find the system very valuable, and the problem leads one on from one thing to another. The more thought that is bestowed, not only on telephones but on telegraphs and other things, the simpler they can be made. In order to prove that these telephones superimposed on telegraphs, and vice versa, are not by any means so complicated as we have been led to believe by some of the speakers, I instrument being at each end. On that composite circuit there are 12 telephones linked at various points across the line, so that it will be seen that it is not by any means a complicated apparatus. The single-needle circuit is from earth, to the Waterloo single-needle instrument, thence in parallel through the two bridging coils (750 ohms each) at Waterloo, the two line wires (435 ohms each), to the two bridging coils (735 ohms each) at Southampton, to the single-needle instrument and earth at Southampton. The only necessity being to keep the

parallel paths through bridging coils and line wires equal to each other, if there is a difference of 1 ohm between the two paths the single-needle signals are perceptible in listened for, but if the difference is 5 ohms the single-needle signals can be distinctly heard on the telephone. Thus we have a telegraph circuit and a telephone circuit on the two wires. The telephone circuit is connected to the switchboard at Waterloo, on which there are about 250 connections, and to the switchboard at Southampton where there are 200 extensions, also to small switchboards at the intermediate stations, and any of those extensions can speak over that line from one end to the other. We have arranged battery ringing on the telephone circuit, and any one of the 10 intermediate stations on the line can, by means of polarized ringing currents, be called without interfering with the Waterloo switchboard. Similarly, by an arrangement requiring one long ring as a code call for Southampton switchboard, the calls for intermediate stations do not affect the Southampton switchboard, but all the code calls on the circuit affect the intermediate instruments. We have a number of similar circuits all over the line.

Mr. G. Robinson: There are one or two matters of detail which it may be of interest to mention. One objection to phantom working referred to by a previous speaker is the lack of automatic signalling on phantom circuits and on side circuits. In 1914 the Post Office worked out a system in the laboratory which appeared to be satisfactory, but progress was stopped by the war. Since then the work has been taken up again and a satisfactory system has been evolved. We hope to try it in commercial practice soon. With regard to Fig. 12, it is interesting to note that the frequency intervals between successive maxima and minima of the frequency/impedance curve occur at fairly regular intervals. It is quite simple to calculate the distance of the fault causing these humps, and this gives an easy way of clearing up lines which are required for repeater working or for superimposing. With regard to filters, the first consideration in their design is the calculation of the cut-off points, and the usefulness of the paper would, I think, be increased if an expression were added giving these cut-off points. It can be derived by equating the expression for $\cosh\theta$ to $+1$ and -1, since between these two limits occurs the efficient range or ranges of the filter. When the values of the inductance and capacity giving the desired cut-off points and impedance have been obtained, it is fairly easy to adjust the resistance so as to obtain a sharp cut-off and also high efficiency over the effective range of the filter. I should like to mention two types of filter which I do not think have been previously noticed. They both employ mutual inductance and capacity. The first is that shown in Fig. 13 (f). If the mutual inductance is made negative, the filter consists of a series of sections similar to Campbell's filter for eliminating a single frequency. If the coupling is close this frequency is the same as the cut-off frequency of the filter. By employing this arrangement we are able to obtain a filter with a high efficiency over the effective range and with a sharp cut-off. These characteristics depend less upon the effective resistance than in other types of filter. The second type of filter I wish to mention consists of a series of transformers with one condenser in each section. If these quantities are inserted in the equations given in the paper it will be found that this gives a band filter, which, however, employs fewer parts than any other type of filter that I know of, there being only one inductance and one condenser in each section. One other point which I should like to mention was referred to by Mr. Hart, namely, the choice of transformers for superimposing. The trouble of transmitting noise from an unbalanced circuit to a balanced circuit through the transformer is avoided if the transformer is screened, and no sacrifice of efficiency is entailed if this method is adopted.

Mr. G. C. Marris: There are one or two points on which I should like to have further information. With regard to Fig. 3 showing the rise of current, how do the curves for the various machine telegraphs compare with those given for the Wheatstone? The fact that we have heard to-night that machine telegraphs are used on these composited circuits indicates that it is possible to use such machines. It would be interesting to know whether in this country any machine telegraphs have been superimposed in the second way shown in Fig. 8, simply by the use of transformers as used for phantom telephone circuits. I should like to know what has been the maximum speed practicable on such a circuit. With regard to the remarks on page 685 about the degree of amplification allowable with a telephone relay, is there now any evidence on which to revise the accepted figures of magnification? These appear at present, both in this country and America, to be a ratio (output/input) of about 5 : 1 for 2-wire repeaters, and 30 or 40 : 1 for 4-wire repeaters. There is a big difference between these two, and one wonders if 5 to 1 is really the limit for 2-wire working which the cables, allowing for phantom circuit cross-talk, will stand, or if there is hope of raising the figure. It would be interesting if the author could say whether all the circuits in a cable can be balanced for repeater operation by the same values of artificial balance, or if the variations are great enough to make individual balancing necessary. Referring to the use of relays and repeaters, I am inclined to wonder whether the composite type of telegraph–telephone circuit could not obtain a new lease of life, apart from the use of filters, by employing a valve relay on the telegraph circuit itself. It seems to me that a valve relay designed for low-frequency or aperiodic magnification would enable a telegraph circuit to be operated with such small voltages that it would give less trouble from disturbance. Finally, I was rather puzzled by the remarks made by the author as to the method of signalling with these phantom circuits using a frequency of 150, for in another place he speaks of the filters which apparently cut off any frequency below about 300. It appears to me that it might be necessary to push the signalling frequency much higher than 150 and use high-frequency relays, as had been done with wireless circuits where relays mechanically tuned up to frequencies as high as 1 000 per second have been used since an early date.

Captain F. Reid: I desire first to refer to the spacing

of loading coils. On page 683 the author quotes the formula $CDL = 25$, and explains that if the loading coils are spaced wider than this the high frequencies are attenuated too much. I understand that, with this spacing, frequencies below 2 000 are transmitted quite freely. On the other hand, when it comes to the question of filters, on page 685 he explains that repeaters can work if all frequencies above 1 300 or 1 400 are cut off. If quite clear speech can be obtained without frequencies above 1 400, why space the loading coils so closely? Why not use a larger inductance coil and space it 20 or 25 per cent more and thus save money? Another point with which I should like to deal is the question of overhearing and cross-talk in underground cables. On page 687 the author explains that the use of relays makes it necessary to balance cables to a finer degree even than before, and that the cross-talk must be still further reduced. At present the cross-talk between the phantom and the side circuit has been reduced to less than that between the phantoms in different cores. It is possible to go on indefinitely reducing the out-of-balance in the same core, but I do not know any method whereby it is possible to go on indefinitely reducing the cross-talk between phantom and phantom in different cores, and I should be glad to know if the author is acquainted with any method. I should like next to deal with the capacity variation in cable circuits. The author suggests a figure of $1\frac{1}{2}$ per cent as the variation from mean capacity. At present we get variations of the order of 10 to 15 per cent in single lengths, and up to 5 per cent in completed loading-coil sections. Part of the trouble is due to the fact that it is usual to specify at present simply that the mean capacity of a cable shall not exceed a certain figure. Contractors interpret this in different ways. One contractor makes a very efficient cable with all circuits of low capacity. Very few of the circuits exceed the maximum fixed for the mean capacity. His neighbour, on the other hand, takes the specification literally and has some circuits very much higher and some very much lower. When we happen to get the two sections joined together—the one of the generous contractor who has given a very low-capacity cable, and the other which just complies with the specification—we get a big difference in capacity and, therefore, a reflection at the junction of the sections. I think it is important that cable manufacturers should consult together so as to standardize the capacity for a given specified type of cable and also to fix the limits of capacity variation, because we do not want to do all the balancing on the road.

Mr. P. E. Erikson (*communicated*): Mr. Hill refers on page 686 to a German method of balancing capacities in cables by the addition of small condensers. I think it is only fair to state that this method has long been known to telephone engineers both in this country and in America. It has been used in America since 1911 for armoured cable sections, laid in estuary and river crossings, where it is important that no joints be inserted in the armoured section. Aside from these special instances, it is not considered to be as efficient as the balancing method, disclosed in British Patents No. 2 009 and No. 2 508, or the method shown in Fig. 11 in the author's paper. Some of the objections to the condenser method of balancing are:—

(1) The addition of condensers adds to the cost of the cable. In the cross-splicing method existing capacity values in the cable sections are made to balance each other, thus involving no extra expense for additional apparatus.

(2) Installation and maintenance are complicated by the presence of the condensers. If, at any time, a section of the balanced cable has to be replaced, a new set of condensers must be provided, when the cable is again balanced out.

(3) The cross-talk between circuits in adjacent quads is objectionable when this method is followed, unless the unbalances between phantom and phantom are also corrected by adding condensers. This added complication renders this method very costly in comparison with the cross-splicing method. Likewise, if it were desired to balance the circuits to earth, matters would be further complicated.

For the above reasons the method of adding condensers is only used in America where the physical conditions prevent the use of the simpler and more efficient method. In America it has not been found necessary in quadded cable, even when equipped with composited telegraph circuits, to make special tests in the field to balance the two conductors of the pairs to earth. This leads me to inquire why it is considered necessary to take special precautions to balance the pairs to earth, when no precautions are taken to balance the phantom to earth, as the phantom circuits are inherently more poorly balanced than the pair circuits. Now with reference to the uniformity of capacity in successive loading sections, the author on page 688 refers to some experiments which are said to have been made in Germany on coil-loaded cables, and which point to the fact that the electrostatic capacity should not differ from the mean value by more than $1\frac{1}{2}$ per cent. This problem of maintaining a uniform capacity is a very difficult one, but a good deal depends on the uniformity of the cable itself. I think it is safe to say that half-a-dozen cable manufacturers, who work to a specified mean value of mutual capacity, would produce cables the maximum and minimum mutual capacity values of which, if the test data were examined, would be found to vary widely one from the other. Different machinery, differences in material, different designs and different manufacturing methods are largely responsible for this condition of affairs. As the author points out, this problem has been studied in America, but the Bell system in America gets all its cable from one manufacturer and, to that extent, the variations in the capacity values are placed under the control of one designer and manufacturer. In this country and in Europe generally, this state of affairs rarely obtains. Contracts for long-distance cables, and by that I mean cables of 150–200 miles, or longer, are frequently divided among two or more cable makers. For the reasons just mentioned the deviation in capacity between the products of the various makers is bound to be great. I have in mind the result obtained by two cable makers,

working to the same specified mean mutual capacity value. In one instance, this variation amounted to 19 per cent between the maximum and mean values and 9 per cent between the mean and the minimum values. In the other case the difference between maximum and mean was 15 per cent and the difference between the mean and minimum $13\frac{1}{2}$ per cent. These values all refer to factory lengths. This raises the question whether it would not be policy for the operating company, or telephone administration, to award its contracts for long-distance cables in such a manner as to make one contractor responsible for a continuous run of cable between two trunk centres; another contractor for another run between two other trunk centres, and so forth. This would at least be a step in the right direction towards uniformity of the product. In addition to what may be accomplished in the factory, however, there are other means of obtaining the desired uniformity. One method of doing this is the equalization of capacity values by testing for mutual capacity the sections of cable which go to make up a loading section and to joint them so as to give the desired uniformity, in addition to balancing the section for capacity as already described. In fact, the two processes can be carried out simultaneously. This method is disclosed in U.S. Patents No. 1 375 405, issued to W. H. Martin, and No. 1 375 414, issued to H. S. Osborne. In this connection I might also say that after the irregularities in capacity balance and mutual capacity have been taken care of in a loading section, there is another irregularity which must be given some consideration in order that sufficient uniformity may be obtained for successful repeater operation. Practical conditions often make it difficult to design a loaded line system so that the loading coils come exactly at calculated points. Means must therefore be provided to equalize loading sections electrically, and this has particular reference to the capacity values of each loading section. This has been done by so-called building-out sections, which are essentially condensers, shunted across the pairs, these condensers having such values as to correct deficiencies both as regards the phantom and the side circuits. The method is fully described in U.S. Patent No. 1 219 760, issued to Mills and Hoyt.

Mr. W. J. Medlyn (*communicated*): As a matter of history, it may be of interest to mention that the composite arrangement described on page 679 was first tried experimentally in November 1899 on a line connecting four country post-offices with the head office at Leeds, the wires being erected on a main telegraph route carrying high-speed circuits. The immediate object was to displace the A.B.C. telegraph apparatus previously in use, and thus simplify the operating work and reduce maintenance costs. In March 1900, owing to a breakdown of overhead wires due to a severe snowstorm, telegraphic communication between Leeds and York was entirely interrupted. One telephone trunk circuit was workable between these two centres, and on this a Wheatstone circuit was superposed; a speed of 200 words per minute was maintained, the line being also in use simultaneously for telephone trunk working. In 1901 the system was extended to a considerable number of country post-offices throughout the provinces; the results were satisfactory, and further extensions have since been made. It was originally foreshadowed that the arrangement would probably prove useful for linking up country offices with the telephone trunk system where the traffic receipts would be insufficient to justify the cost of erecting independent telephone wires for the purpose; and this anticipation has been realized to a considerable extent. The transmission efficiency is, of course, much below that which is obtained with standard telephone line construction, and it is generally necessary to limit the calls to places within a distance of about 40 to 100 miles, the conditions in this respect varying according to the local circumstances.

Mr. F. Mercer (*communicated*): Having been associated since 1914 with the balancing of trunk telephone cables, I am very interested in the section of the paper which deals with that subject, and particularly in the author's reference on page 686 to Messrs. Siemens and Halske's patent for balancing by means of condensers. The impression conveyed is that the principle is entirely new, whereas this is not the case, for the method disclosed in the patent was actually put forward to the Post Office in 1914 by Messrs. British Insulated & Helsby Cables, Ltd., as a solution of the balancing question before the present system involving double bridge tests was evolved, and at a time when earlier methods had not proved successful. I believe that the use of separate balancing condensers was not entertained at that time by Post Office engineers, as it was desired to avoid as far as possible connecting auxiliary apparatus into cable systems. Moreover, the author will recall that on some loading-coil sections between Birmingham and Liverpool of the pioneer balanced trunk cable between London and Liverpool, the results obtained for capacity balance were in some cases rather over specification limits. In order to bring them within these limits adjustable condensers were introduced into one or two joints per loading-coil section. I should like the author to explain the reasons for a limitation in the value of earth capacity unbalance. It is by no means clear that such a limitation is necessary because it can be proved theoretically (see *Journal of the Institution of Post Office Electrical Engineers*, 1914, vol. 7, p. 41) that the only necessary qualification for the reduction of overhearing and cross-talk is that the net capacities between A and C, B and C, B and D, and D and A (Fig. 11), measured with all other conductors in the cable insulated, should be equal; that is to say, it appears to me that a specification for capacity unbalance need only call for a limitation in respect of W–X, Z–Y, W–Z and X–Y, where W, X, Y and Z are the net capacities in contradistinction to the direct capacities (w, x, y and z) between A and C, B, and C, B and D, and A and D, respectively.

Mr. A. B. Morice (*communicated*): The paragraph in the paper to which I desire to refer briefly is on page 687, under the heading "Continuously Loaded Cables. Difficulties in Balancing." It will be noticed that this subject is at present receiving special study in the British Post Office, and I think that the most useful part which I can take in the discussion is to place before the meeting some of the results already obtained

in reducing the interference between side and superimposed circuits in continuously loaded submarine cables. Two methods have been used to tackle the problem, as follows :

Method (1).—A measurement is made of the alternating-current unbalances of resistance, inductance, leakance, and capacity of lengths of unsheathed quad core, and these lengths are then joined up in such a way as to reduce the residual unbalances to the smallest possible values. This method may be termed "Length Balancing."

Method (2).—Suitable balancing impedances are placed at the ends of the cable, designed from actual impedance measurements of the cable over a range of frequencies. This method may be termed " End Balancing Impedance Method."

I understand that Method (2) will be referred to later in the discussion so I propose to confine my remarks to Method (1) as used in the case of two recent submarine cables. Referring for a moment to the theory of this method, I would call attention to Fig. 11(*b*) of the paper, which represents the diagram of capacities for a dry-core paper cable quad. Now, in the submarine cable the capacities w, x, y, z, m, and n do not exist and we are simply left with those marked a, b, c, and d. The conditions, then, for no interference, due to capacity unbalance, between the side circuits or between either side circuit and the superimposed circuit shown in Fig. 11(*a*) are that $a - b = 0$ and $c - d = 0$. In a continuously loaded submarine cable, however, we must also deal with interference caused by unbalance in effective resistance, inductance and leakance, as well as that due to capacity unbalance. If *a*, *b*, *c*, and *d* are also used to represent the effective resistance, inductance, and leakance of the corresponding cores of the cable, then the conditions $a - b = 0$ and $c - d = 0$ must also hold for these latter three quantities in order to prevent interference. These theoretical conditions assume that the four alternating-current constants of each of the cable cores are uniform along their length, and of course this assumption never holds exactly in practice.

Let me now proceed to refer to the two recent submarine cables in which " Length Balancing " was adopted. The first cable was a four-wire cable having the following constants :

Copper conductor weighed 169 lb. per naut.
Dielectric weighed 195 lb. per naut.

D.C. Resistance 14·6 ohms D.C. Capacity 0·195 μF	per naut loop.
A.C. Resistance 16·6 ohms A.C. Capacity 0·195 μF A.C. Leakance 3·9 micro-mhos A.C. Inductance 24·5 milli-henrys	per naut loop. (Frequency = 800 ∼ per sec.)

Characteristic Impedance = 356|3° 43′

This cable was manufactured in three sections of similar length, the first two sections not being balanced. As the overhearing between the two side circuits and the superimposed circuit in these two sections was too high for commercial purposes, it was decided to reduce it in the third section as far as possible by length balancing. For practical reasons it is not considered advisable to cut submarine cables in shorter lengths than necessary, so measurements were first made on 1-naut lengths. It was found, however, that a.c. leakance and capacity unbalances were in a number of instances so different when testing from the two ends of the length, that it was necessary to balance in $\frac{1}{2}$-naut lengths if a reasonable diminution in the overhearing was to be obtained. This was accordingly done and the following results indicate clearly the improvement effected.

Cable section No.	Description of section	Interference between	Measured interference expressed as speech equivalent through standard cable		
			Minimum M.S.C.	Maximum M.S.C.	Mean M.S.C.
I.	10 nauts unbalanced	Side circuit and side circuit ..	86·0	88·0	86·9
		Side circuits and superimposed circuit	43·5	52·1	48·3
II.	10 nauts unbalanced	Side circuit and side circuit ..	87·9	90·3	89·0
		Side circuits and superimposed circuit	39·6	52·1	45·0
III.	$7\frac{1}{2}$ nauts balanced in $\frac{1}{2}$-naut sections	Side circuit and side circuit ..	93·4	95·5	95·0
		Side circuits and superimposed circuit	52·1	78·3	63·1

The second cable was a 28-wire submarine cable having the following constants :

Copper conductor weighed 70 lb. per naut.
Dielectric weighed 110 lb. per naut.

A.C. Resistance 32 ohms A.C. Capacity 0·139 μF A.C. Leakance 9 micro-mhos A.C. Inductance 20 milli-henrys	per naut loop. (Frequency = 800 ∼ per sec.)

Characteristic Impedance 387|8° 30′

This cable was manufactured and balanced in lengths of $\frac{5}{8}$ naut. During the core stage the d.c. capacity of each of the four cores to be stranded into a quad was measured, and the cores were arranged so as to make the d.c. capacity unbalances $(a - b)$ and $(c - d)$ as small as possible. After making up the cable into

quad coils, each $\frac{5}{8}$ naut in length, the a.c. unbalances of effective resistance, inductance, leakance and capacity were measured. During the manufacture of the 28-core cable, selections were made at each $\frac{5}{8}$-naut joint so as to reduce these unbalances to the minimum value possible, the final length of the cable being 10 nauts. The measured overhearing between the side circuits and the superimposed circuit for all the seven quads of this cable was equivalent to speech through from 56·5 to 73·7 miles of standard cable. It will be seen from these results that, by length balancing using $\frac{1}{2}$ to $\frac{5}{8}$-naut lengths, the interference has been reduced to a sufficient extent in a continuously loaded submarine cable to render a non-commercial superimposed circuit suitable for commercial use. This result has been accomplished with copper core weighing only 70 lb. per naut and loaded with 20 mH per naut. The heavier the conductor core and the smaller the loading inductance, other things being equal, the smaller the residual overhearing that can be produced by length balancing. It will have been observed that my reference has been to length balancing of continuously loaded submarine cables, yet that of continuously loaded underground cables is similar, with the following differences: (*a*) The capacity network for a quad is more complicated in the case of A.S.P.C.* underground cable, being as shown in Fig. 11(*b*) of the paper; the magnitude of the actual capacities involved, however, is greater in the case of the submarine cable. (*b*) Leakance in A.S.P.C. underground cable is usually very much smaller than in a submarine cable and its effect in the former cable in producing interference can be made negligible. The superimposed circuit referred to throughout these remarks is the one shown in Fig. 11(*a*) of the paper, and it may be of interest to remark, in conclusion, that this superimposed circuit has, in the case of a continuously loaded submarine cable, a transmission efficiency equal to or slightly greater than that of the side circuit.

Mr. A. Morris (*communicated*): In forming an extra channel of communication over an existing line it is necessary to ensure not only the requisite transmission efficiency for each of the channels, but also that there shall be no interference between them. The description of the methods adopted in the solution of these problems, for the different conditions under which they arise, occupies an important place in this paper. In superposing on loaded telephone circuits serious overhearing and cross-talk will occur unless the impedances of the limbs of such circuits are equal at all points equidistant from the sending end. This is extremely important and is clearly pointed out by the author. To secure equality of these impedances, in magnitude and phase angle, at all frequencies, uniform distribution of and complete balance of the electrical constants over the whole length of the circuits is essential. In order to secure this, in coil-loaded underground circuits, it is the practice to deal indepedently with the cable, loading coils and terminal repeating coils and to balance each separately for capacity, conductor resistance, inductance and leakance. Terminal repeating coils, as mentioned in the paper, are used for the purpose of forming the phantom circuit upon the two side circuits of a two-pair combination. They serve other important functions, however, namely: (i) Interposed between the line and local sides of the circuit terminals they prevent conduction of any unbalanced currents (introduced by the exchange equipment) to the balanced line. (ii) Disturbances to the main line, which may be electrostatically induced by the local plant, can be eliminated by the use of an earthed metallic screen between the primary and secondary windings of the repeating coil. This has been pointed out by a previous speaker. (iii) With suitably designed primary and secondary windings the inevitable transmission losses associated with such terminal apparatus may be reduced to a minimum. (iv) By the use of terminal repeating coils the exchange-cabling and apparatus can be readily disconnected from the underground cable. The maintenance-testing of main trunk cables, which are normally of very high insulation resistance, and which can thus be completely isolated, is thereby greatly facilitated and rendered very precise. In balancing multi-twin cables the "crossing method" is the one in general use in this country. It is based upon the principle of the neutralization of the electrical inequalities in consecutive lengths of line whereby the unbalances, and therefore the disturbances, as soon as they arise in one length of cable are cancelled out or reduced in the next. An alternative to this method consists in the addition of suitable condensers, leaks, resistances, etc., as the case may warrant, at various intermediate points along the circuit. This method, which might be termed the "auxiliary apparatus method," has been referred to by the author in connection with British Patent No. 147 013 of 1920, applied for by Messrs. Siemens and Halske. Unless the positions at which this apparatus is introduced are suitably chosen in regard to the inequalities, the resulting balance will be non-uniform and imperfect over the range of speech frequencies. Overhearing will therefore not be completely eliminated. Further objections to this method from the constructional and maintenance point of view may be urged, and its application to main underground trunk cables is, accordingly, definitely prohibited. The principle involved in the auxiliary apparatus method of balancing is, of course, not new. For a number of years it has been used for the elimination of disturbances in circumstances where the above objections do not operate. Quite recently the principle has been successfully extended to the design of special balancing circuits, operating over a range of frequencies, at the ends of submarine cables for the purpose of eliminating disturbance between the side and phantom circuits. The author has paid a well-deserved tribute to the successful manner in which British contractors have co-operated in the production of balanced telephone circuits. The subject is continually progressive and improved standards of manufacture and construction of the plant are constantly being demanded. Great improvements have already been effected in cable manufacture, but it is thought that even better results will be required in the future. Improvement will probably be along the lines of greater uniformity in cable circuits and in the exercise of better control over

* Air-space paper core.

manufacturing irregularities. There is already an urgent need for a much smaller variation in the mutual electrostatic capacity of cable pairs, not only in the same cable length but between different cable lengths. The experiments of Wagner and Küpfmüller point to a permissible variation for circuits between loading coils, not exceeding 1·5 per cent of the mean. In view of the magnitude of the variations which are generally found to exist between the capacities of the various circuits of single cable lengths, it is doubtful whether this figure could be obtained at present without special balancing during jointing operations on the road. Improvements in the mechanical design of cables and in cable-making machinery for the purpose of readily securing correct geometrical twinning of wires and pairs and regularity of stranding will doubtless contribute to the solution of this difficulty in regard to electrostatic capacity, while greater uniformity and care throughout the whole of the operations involved in the production of copper wires will effect the necessary improvements in the conductor resistance of modern light-gauge cable circuits.

Mr. E. S. Ritter (*communicated*): On page 683 the author speaks of transmission loss as "core loss" when referring to a particular type of transformer. I consider the expression "core loss" to be misleading, as usually meaning the iron loss, whereas in this particular case at least 90 per cent of the loss at speech frequencies is in the copper windings and should therefore be more properly designated "copper loss." On page 685 cross-talk and overhearing are referred to in connection with telephonic repeaters. I am unable to agree with the statements made, and in order to make a reasoned criticism I must go rather outside the scope of the paper. To provide a satisfactory telephone service it is at least necessary to arrange for: (1) Subscribers communicating with one another with speed, accuracy and a minimum of trouble, i.e. a minimum of delay in setting up a connection. (2) Good transmission when a connection has been established, i.e. loud, clear speech with the absence of disturbing noises between the terminal points. (3) A reasonable cost of furnishing the service and a low charge, having regard to the facilities given. The paper is particularly concerned with that portion of the circuit used for long-distance communication, phantoming circuits having a direct bearing on item (3) in reducing cost. Now, in order to fulfil condition (2) not only the long-distance lines and the apparatus used with them but also the subscriber's instrument, local line and junctions, including the associated exchange apparatus must be designed, constructed and maintained to a good standard of speech transmission. The author does not appear to draw attention to these most essential points. Whilst it is possible to provide satisfactory communication with a line free from extraneous disturbance, the attenuation of which is greater than may ordinarily be desirable, yet the introduction of disturbance due to overhearing, cross-talk, induction from telegraph and power circuits, etc., will necessitate the provision of a line of considerably greater efficiency. My remarks will now be confined to disturbances introduced by adjacent telephone circuits. Consider two circuits AB and CD (Fig. D), A and C being one end and B and D the other. Assume that overhearing or cross-talk which, measured from end AC, amounting to the equivalent of speech transmitted through, say, 80 miles of standard cable, exists between those circuits. If the equivalent of 10 miles of standard cable (m.s.c.) be inserted either between the disturbing source and the end A or between the listening telephone and the end C the effective value of the cross-talk will become 90 miles. If 10 m.s.c. be inserted in both circuits the effective cross-talk will be equivalent to direct speech through 100 miles. If the line from A to B and from C to D is, say, 8 m.s.c., then, assuming the overhearing is concentrated at the end AC, speaking at A and listening at D, overhearing of 88 miles will be found, or if disturbing at B and listening at D, 96 miles. It may therefore be concluded that in a simple line of this sort the worst cross-talk will occur when disturbing and listening at the same end of the line and where the overhearing is concentrated at that end. Assuming that a satisfactory service has been given in the past between two towns directly connected, the introduction of new lines and telephonic repeaters will furnish the same overall transmission as before. Consider two circuits DEF and GHK replacing AB and CD in the previous example, the lines DE, EF, GH and HK each being equivalent to 10 m.s.c. At E and H is a repeater

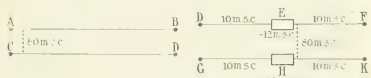


FIG. D.

giving an amplification of 12 miles, thus reducing the 20 miles between D and F or G and K to 8 miles. Consider a leak between the two circuits equivalent to 80 m.s.c. on the FK side of the repeaters at EH. Speech enters at D; it is attenuated by 10 miles to E, amplified 12 miles at E, and is therefore 2 miles better than speech entering at D. After leaking into the other circuit through 80 m.s.c. it is reduced to 78 miles, amplified by H to 66 miles, and attenuated by G to 76 miles, hence the cross-talk is 4 miles more than if it had occurred at DG, or twice the amount that the repeater has amplified the energy over and above the amount entering the line at D. Now the author has assumed that the energy is amplified to an amount equal to the energy entering the line; in which case he does not appear to justify the need of a greater degree of accuracy of capacity balance; nor is the statement justified that the mean voltage in a relayed circuit is greater than in the unrelayed one (provided the two have the same overall efficiency), except as regards the extra amplification of the repeaters of 2 m.s.c. in the example taken. Experience has led me to the conclusion that the worst cases of overhearing or cross-talk occur between the phantom and loop circuits upon which it is superposed and between loops and phantom circuits, which may run adjacent for some considerable distance. The latter condition needs special attention where a small group of circuits are always adjacent, as in the

case of a 14-pair M.T.* cable or 14-pair centre of a larger cable where for any reason it is not possible in the balancing operations to mix them with the remainder of the cable, and thus minimize the amount of propinquity. In connection with 4-wire working I agree that it is essential that no overhearing or cross-talk should exist between "Go" and "Return" elements. If the phantoms are worked in the same direction as the loops this system would appear to be superior to the 2-wire system as regards disturbances, because there is always the length of line between repeater stations to cut down disturbance. Conditions arise where disturbances may become important, e.g. terminating circuits at an intermediate point adjacent to a repeater station, and such cases should receive special attention. Finally, I wish to emphasize the desirability of working phantom circuits and the loop circuits upon which they are superposed between the same terminal points, and also repeating them in the same repeater stations.

Mr. E. V. Smart (*communicated*): Comment has already been made by one speaker on the different capacity values obtained from various manufacturers; actual recent experience, however, indicates that one manufacturer can obtain widely varying results in approximately equal lengths of the same type of cable, also that in many lengths where the average capacity unbalance is fairly good there are to be found cores with very high values indeed. These facts point to the desirability of limiting not only the capacity, but the range of capacity unbalance; also the desirability of manufacturing and supplying lengths of cable in the order of the schedule supplied and not in discontinuous lengths such as to render the matching of capacity unbalances unnecessarily difficult. As an example of a core of high value not comparable with any core in its own length or with its namesake in any length of the same loading-coil section, I give the following:

Length No.	p-q value	Cores in the same layer	p-q value
1	50	O	+ 20
2	0	B_1	− 20
3	0	W_1	− 55
4	− 20	R_2	+ 15
5	+ 50	B_2	− 20
6	+ 30	W_2	− 385
7	− 15	R_3	+ 10
8	− 20	B_3	+ 40
9	+ 25	W_3	− 40
10	− 385	R_4	+ 20
11	− 35	B_4	10
12	− 15	W_4	− 50
13	+ 15	R_5	− 5
14	− 15	B_5	− 40
15	− 30	W_5	− 75
16	− 10	G	+ 80

Now this p-q value of − 385 spoils the whole loading-coil section, and the acceptance of lengths with such values is a matter of consideration.

Mr. H. T. Werren (*communicated*): On page 684 the author has referred to his method for ascertaining the most economical combination of loading coils and cable to give a required transmission value. It is to be hoped that as soon as sufficient data are available he will give us the benefit of his wide experience and show us how to calculate the most economical combination of cable, loading coils, and repeater stations. The author has on page 687 referred to the problem of balancing continuously loaded cables. This is certainly more complex than in the case of coil-loaded cables and I should like to say a few words with reference to it. Experiments show that a good deal can be done towards effecting a balance by measurements of capacity and inductance on $\frac{1}{2}$- or $\frac{5}{8}$-knot lengths in the factory before sheathing, and suitable crossing of wires at the joints, and that subsequent sheathing operations do not materially alter the cross-talk. Further, some very encouraging results have recently been obtained in experiments in balancing long lengths of completed cable from the ends. The overhearing between a side circuit and a phantom circuit in a core of submarine cable is of course due to the impedances to earth of the A and B wires forming the side circuit being unequal, and measurements on a continuously loaded cable show that these impedances vary very considerably both in magnitude and in angle with the frequency of the testing current. By shunting the A line to earth with a fixed impedance and shunting the B line to earth with a variable impedance, the overhearing between this side circuit and the superposed circuit can be entirely eliminated at any one frequency, by adjusting the variable impedance. Measurements have been made in this manner on a 30-knot length of continuously loaded submarine cable terminated with transformers and suitable impedances. The fixed impedance shunting the A line to earth consisted of 4 000 ohms in parallel with 0·025 μF, and values were obtained for the impedance required to shunt the B line to earth, in order entirely to eliminate overhearing at all frequencies between 3 000 radians and 14 000 radians per second, measurements being made at frequency intervals of 250 radians. From these values, an impedance/frequency curve was plotted, the real and unreal parts of the impedance being plotted separately, and was found to consist of five irregular humps. The problem was therefore to design an artificial circuit, the impedance of which would closely resemble this curve at all frequencies. Several methods were considered, and on account of the irregularity of the impedance it was decided to reproduce each hump by means of a resonating circuit consisting of resistance, inductance and capacity, such resonating circuits being joined in series. A method of calculating the required values of R, L, and C has been devised by Mr. C. Robinson, with the result that the impedance/frequency curve obtained by measurements on the cable in the manner described has been very closely reproduced on an artificial circuit consisting of five resonating circuits joined in series. Further experiments are being carried out. At the bottom of page 685, the author mentions that an insulation of 10 000 megohms per mile per wire is now obtainable when measured by direct current. I think perhaps it is not generally known why this high figure is insisted on by the Post Office Engineering Department. It is

* Multiple twin.

mainly from the point of view of maintenance. As stated in the paper, the introduction of the telephone repeater has resulted in a considerable reduction in the weight of conductor, and a corresponding increase in the number of circuits carried in a single cable. It will be appreciated that the breakdown of a cable carrying 308 side circuits, with a possible 154 superposed circuits, would be a serious matter, and the maintenance of such a cable with a view to preventing breakdown becomes vitally important. This matter has received considerable attention, and it is now possible to locate accurately a fault in its incipient stage, i.e. when the resistance of the fault is of the order of several hundred megohms. Time will not permit the details of the methods employed being given here. It is well known, however, that when the resistance of the fault is comparable with the normal insulation of the line under test, then the ordinary Varley or Murray loop test will result in an error in the location which may be equivalent to many miles, and until recently there has been no alternative but to wait until the fault has developed before accurate location tests could be made. This materially increased the risk of a complete breakdown of the cable. Methods and extremely simple formulæ have now been evolved by the Department, whereby tests from both ends of the line will give the position of a fault of two or three hundred megohms' resistance, to within about two lengths of cable on a line, say, 100 miles in length. Careful periodical maintenance tests will indicate the presence of such a fault in its incipient stage if the normal insulation of the cable is of the order of 10 000 megohms per mile per wire, and by means of the methods just referred to such faults can be located and cleared before they have developed sufficiently to interrupt traffic. These methods have passed the experimental stage, and are now in operation in every Superintending Engineer's district throughout the country.

Mr. J. G. Hill (*in reply, communicated*) : A number of speakers have contributed a considerable quantity of historical and technical information which, while it does not call for reply, adds materially to the value of the paper and discussion. Incidentally, it is evident from the technical information given that a large amount of valuable work is done which in ordinary circumstances would not see the light.

Mr. Thompson has contributed some interesting and valuable information, but his criticisms call for some comment. In comparing the two systems of superposing discussed, it should be borne in mind that the simplexed system, which is an equipotential system, is capable of giving a much higher telegraph speed on a well-balanced circuit than is the composited system. Where the telephone circuit is perfectly balanced, an impedance (or filter) in the telegraph circuit is not necessary and a quiet telephone circuit is obtained. Even where unbalance exists a simpler filter permitting much higher frequencies than in the composited case is usually possible, and it follows that the advantages claimed for the composited system must be materially reduced. Again, we are told that the simplexed circuit is obtained at the expense of the valuable phantom facility; but it is known that a phantom circuit can carry 4 composited circuits, and we have only to work the 2 lines constituting each side circuit in parallel (instead of separately as in the composited arrangement) to obtain 2 simplexed circuits superposed on a phantom circuit, which latter circuit should be at least as good as a phantom which carries 4 composited circuits. I was not aware that combined phantom and composited working had been used in Denmark; the introduction is, however, quite recent. I could hardly be expected to include in my review secret war circuits of another nation. Paragraphs (1) to (4) in Mr. Thompson's statement call for a reply. As regards (1), Mr. Thompson has furnished a probable reply to his question in the same paragraph, and this is correct. The capacities used are 4 μF and 8 μF. The alternative to the arrangement in Fig. 7 is to bridge the telegraph circuits on the A and B lines of the telephone circuits. This has been found experimentally to involve (*a*) a greater transmission loss, and (*b*) a greater degree of circuit unbalance than the arrangement in Fig. 7. It must be remembered that in open-circuit telegraph working where currents are sometimes circulating in the circuit and sometimes are not, differences of impedance to currents of telephonic frequency may to some degree arise, and these are reduced to a minimum by placing the composited circuits as near as possible to the centre of the circuit. As regards (2) we are here told what happens in the American circuit; but sufficient data are not given to permit of a useful comparison with Fig. 7. For example, neither the inductance of the filter nor the method of working adopted in America is given. With reference to (3) the reply is that the higher frequencies in the composited circuit are cut off by the filter, and the impedance of the condenser at D (Fig. 7) is sufficiently high to the remaining lower frequencies to prevent appreciable interference between the two telegraph sets. As regards (4) if in any case (as in aerial lines) there is any possibility of circuit unbalance, the division of the condenser at D (Fig. 7) into two condensers earthed at the middle point may cause more difficulty in the telephone circuit by induction from extraneous sources than is compensated for by cutting off one telegraph circuit effectively from the other. Where there is any advantage in using the earth it is adopted in this country. The number of composited circuits in Great Britain is very small, but I cannot give the exact number. There is, however, now a standardized diagram in this country for applying Fig. 7 where it can be used with advantage, and it may be modified to suit local circumstances. Both legs of the circuit have certainly and successfully been simultaneously used as stated under "Composited Circuits" in the paper. Mr. Thompson says: "It has been alleged that the composite method is unsuited for this country on account of bad weather conditions." The point of view taken in this paper is not that composite circuits cannot be worked in England, as is evident from the fact that such circuits are shown as being successfully worked, but that the low insulation experienced in this country under winter conditions does not permit of the same favourable results being obtained as are said to be obtained in America, and in my opinion the Euston–Rugby experiment cannot be said to prove the contrary.

The circuit is 84 miles in length, whereas in America 700 miles is said to be a common circuit length. Railway circuits are, in general, favourably situated for good insulation owing to the general absence of trees overhanging the lines, but notwithstanding this the winter total insulation resistance cited by Mr. Thompson, viz. 2 000 ohms, is very low and, if the circuit had been very long and subject to insulation loss similar to that observed, the consequent reduction of impedance and increase of attenuation would have introduced very unfavourable factors for composited working. So far as can be judged, however, the experiment appears to have been quite successful, and to have demonstrated the merits of the composited system used, in the conditions in which it was made. The limitations to which the present system of composited working is subject depend, among other things, on the following factors :—

(1) It cannot be applied to high-speed working (the limit given for Wheatstone working on composite circuits is 60 words per minute) and there are a large number of high-speed circuits in this country.

(2) The maximum advantage cannot be obtained on aerial lines subject to large insulation variation as in Great Britain, because at periods of low insulation a natural telegraph remedy is to increase the voltage, which at the same time increases the noise in the telephone circuit, due to the working telegraph.

(3) The question as to how much noise can be tolerated by telephone users has to be considered, and different standards may obtain in different countries. Even if prejudice comes into question it has to be considered.

(4) Some telegraph systems produce less disturbing effects than others.

Outside these limits there is, however, a wide scope for the use of the composited system. The ultimate best arrangement, taking all factors into consideration (including cost and systems of working) and considering both telegraph and telephone interests, involves considerations beyond the limits of this paper, but I fully recognize the great importance of the subject.

In reply to Mr. Aitken, the term " side " circuit is the accepted modern name. I would call attention to the fact that the American Institute of Electrical Engineers is endeavouring to standardize a number of telephone terms and I have tried to conform to their list. The list of terms was copied in the *Telephone Engineer* of September, 1921. I agree that the subject is very important. For any telephone list of terms to be of maximum utility, however, European as well as American practice ought to be taken into account.

At the suggestion of Mr. Robinson, I have added the more useful cut-off formulæ to the Appendix.

I have no curves referring to the machine telegraphs referred to by Mr. Marris. Simplex Hughes has been used in the past on London–Continental circuits (London–Boulogne–Paris) on the simplexed method of working. In order to limit the disturbance to the telephone circuit in the case of line unbalance, due to unequal insulation on the A and B lines, an impedance was used in the battery lead.

The magnification on 2-wire telephonic relay circuits is limited by the fact that such circuits are 2-way balanced circuits ; the relay balance being only approximately perfect. If the magnification is unduly increased the balance is not sufficiently exact for such large currents, and the relay tends to howl owing to reactions set up in the circuit. The improvement obtained from amplifiers in such circuits may vary between 12 and 22 miles of standard cable. For example, if the relay is in the middle of a long uniform circuit with no abrupt changes of impedance in the telephone frequency-range, the improvement will be relatively great. If the line is relatively short or subject to abrupt impedance-changes the improvement will be much less. In the 4-wire system which is a 1-way arrangement the balance referred to is not required and much greater amplification is possible. There is no immediate prospect of changing the present ratios of input/output, but progress is rapid and such a statement is made with reserve.

As a rule all the circuits in a well-made cable can be balanced for repeater operation by precisely similar artificial networks, although there are exceptions to the rule. Valve amplifiers have already been suggested for telegraph circuits (British Patent 127 651/12 May/19). If used on telegraph single wires on a heavy route carrying high-speed circuits there would be a serious danger of inductive interference with telegraph circuits worked with small currents. As regards the different frequencies, that of 150 periods per second is a telephone signalling frequency ; the frequency such that $2\pi f = 300$ refers to a telegraph filter, designed to cut off frequencies which can be dispensed with above key speed.

In reply to Capt. Reid I may point out that I corrected the frequency of 1 400 on which he bases a criticism, when reading the paper prior to the discussion, so that the point of his criticism as regards the spacing rule is lost. In any case, however, experiment shows that the spacing of coils, based on the rule $CDL = 25$, could not be made greater and may have to be made less in long circuits on account of the " echo " effect.

As regards the cross-talk between phantom circuits, so far as I am aware a systematic method of dealing with this matter has not been published. I think, however, that the double-bridge method of capacity balancing, including the separate determination of earth unbalances, would be suitable for dealing with a problem of this kind. The remainder of Capt. Reid's criticism is dealt with in my reply to Mr. Erikson.

There are three curves on page 677 of the paper, two of which are oscillograms of telegraph signals taken in working conditions. Mr. Hart's reasons for suspecting such curves are anything but convincing. He mentions only two properties of a telegraph signal as affecting its transmission (or otherwise) through a condenser, i.e. direct current and slow, periodic currents ; but of course a third property—the rate of rise of the signal—is all-important. A flat-topped signal may be regarded as including all possible frequencies, many of which would pass through a condenser. Generally speaking, unimpeded telegraph signals have such a shape that they give rise to marked telephonic inductive disturbance, and this would, I think, be sufficient to cause the disturbance referred to by Mr. Hart. As regards the relative efficiency of side and phantom circuits, I am afraid Mr. Hart has misunderstood my meaning. The object I have in view is, I think, clearly stated on

page 681, i.e. to find a criterion which enables one to ascertain by inspection whether a phantom circuit is or is not more efficient than its associated side circuit, and this must be borne in mind in subsequent references to the matter. I see no reason to doubt the accuracy of the rules which I have given.

As regards the difficulties said to arise from the efficiency of the transformer, I do not follow the reason given by Mr. Hart for this efficiency. In any case it would be unfortunate if it were sacrificed. Perhaps Mr. Robinson's remarks on this subject may be of assistance. Filters might be utilized to cut off any disturbing frequencies outside the indispensable telephonic range, where the circuit conditions would justify their use.

Mr. Mercer is of opinion that the paper gives the impression that Messrs. Siemens & Halske's method of balancing is new, and he mentions that I was aware that Messrs. British Insulated & Helsby Cables had anticipated it. I may say that I purposely refrained from commenting on the matter, because I did not feel called upon to put myself in the position of challenging the validity of a patent which does not personally concern me. Not only so, but I cannot say with certainty who was the first to use the method. For example, in addition to the above firm, the Western Electric Co. have stated their claims, and I know that the Post Office made well-authenticated experiments in 1912 which they would probably consider anticipated the patent, and there may be others. I took it that all concerned would protect their interests as they thought fit. The discussion has provided the means of avoiding any misunderstanding on the point. As regards the limitation of the earth capacity unbalance, I think that my reply to Mr. Erikson fairly covers the question; but one other important point may be mentioned. The limitation favoured by Mr. Mercer only permits of correcting the resultant capacity unbalance within a core and then only if the unbalanced components are not too large. The method criticized (that described in Post Office Technical Instruction XIX) of separately balancing all the out-of-balance capacity components in a core is, I think, likely to produce a smaller unbalance between the cores, and this point has its importance.

The reference to the method of balancing capacities in Germany, referred to by Mr. Erikson, was included in my paper to show the state of the art in that country. The question of its previous use is a controversial one which I did not think it proper to introduce (see also my reply to Mr. Mercer). I agree with Mr. Erikson on that point, however. As regards the paragraphs numbered (1), (2) and (3) in his remarks, possibly Mr. Erikson has some reliable information as to cost. I have no information on this point, however, and reserve my opinion on it.

In reply to Mr. Erikson's question as to why special precautions are taken to balance the pairs to earth, and not to balance the phantoms in Great Britain, I would point out that a thorough analysis of the capacity components of a 4-wire core includes the determination of the earth capacities. From the practical point of view, if large out-of-balance components of 4-wire cores are measured by methods which do not measure earth capacities separately, the results expected from any selections indicated by such tests do not always give the predicted values and therefore do not permit of the best possible capacity balancing. This has been found by experience. If, however, the capacity differences so measured are not unduly large, I am of opinion that the simpler single-bridge test suffices. The reason that phantom circuits are not dealt with in the same way is in my opinion because such a procedure involves further complication, which it is desirable to avoid on account of expense until necessity renders it inevitable.

Referring to the difficulties introduced by variations of mutual capacity, Mr. Erikson and Capt. Reid will be interested to learn that some of their proposed reasonable remedies, with others, had already been considered before the paper was written, but as the matter is not definitely settled I consider it advisable not to discuss this question. I think it will be agreed, however, that the difficulties experienced were of sufficient interest to justify inclusion in the paper.

Mr. Ritter says that I have not drawn attention to some essential points. My opinion is, however, that the points which he mentions as essential may fairly be expected to be looked up in available text-books, in the improbable event of their not being known. I do not consider them necessary in a paper of this kind. Mr. Ritter disagrees with my statement that a greater degree of accuracy of capacity balancing is required in 2-wire relayed long-distance circuits than in unrelayed circuits. He bases his disagreement on the supposition that the same overall speech efficiency would be provided in any given circuit between two fixed points, whether relayed or unrelayed; but I do not agree with this supposition. I will suppose as a case favourable to my statement, but quite within a practicable range, that a trunk circuit is required on an underground cable 300 miles long. Such a relayed 2-wire circuit could be provided to give an overall efficiency equivalent to 12 miles of standard cable. Previous to the introduction of telephone relays, however, 12 m.s.c. for such a circuit would have been commercially impracticable, so that the basis of Mr. Ritter's comparison fails. As a matter of fact, the mean efficiency of the circuits provided in a much shorter cable (London–Liverpool) before the introduction of relays much exceeded 12 m.s.c. Not only, therefore, would the mean energy be higher in the relayed cable in the supposed case, but each relay station would be equivalent to a sending end—at which point, as Mr. Ritter points out, most of the cross-talk will occur. Further, the cross-talk would be amplified at each relay station and would be transmitted from one section to another. On the whole, therefore, I see no reason to alter the opinion expressed in the paper. I agree with Mr. Ritter's remarks as to loop and phantom circuits which may run together for a considerable distance.

In reply to Mr. Smart, the limits of capacity unbalance in the specification for balanced underground cables provide a remedy in cases where manufacturers balance the cables made by them. In the case of cables balanced by the Post Office, instances of excessive figures such as those quoted by Mr. Smart do not appear to have been numerous. If and when such is found to be the case, the matter will no doubt be dealt with officially.

THE THERMIONIC TRIODE AS RECTIFIER.

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Summary.

The performances of the triode rectifier arrangements used in wireless telegraphy, with signals of various strengths, and with or without a superposed local heterodyne oscillation, are investigated theoretically and experimentally. The theoretical results throughout are illustrated numerically by reference to a certain well-known pattern of triode, and in the more fundamental cases the theoretical deductions are compared with precise experimental measurements made at low frequency. The agreement is found to be very close. Experimental curves for this pattern of triode are given also in cases where it has not seemed practicable to evolve theoretical formulæ.

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1. Introduction.

In wireless telegraphic practice hitherto the final indicating instrument has nearly always been of a type incapable of being actuated by the high-frequency current in the receiving antenna, or by any magnified copy of it, and therefore requiring some form of rectifier. A rectifier, in wireless parlance, is a conductor which more readily allows current to pass in one direction than in the other; it is an asymmetric conductor such that an alternating P.D. whose mean value is zero produces a current whose mean value is not zero. Any non-return valve device, such as the Dunlop valve of a pneumatic tyre, is of course a rectifier, and is sometimes termed a "perfect" rectifier because negative pressure difference is accompanied by *no* negative flow. Electrical valves of this type are available for use with large E.M.F.'s, as when diodes are used for obtaining a high-tension direct current from an a.c. source; but for the feeble signal E.M.F.'s of wireless receivers no such "perfect" rectifiers have been produced, and rectification depends upon the excess of the current in one direction over the current in the other direction (the latter no longer being sensibly zero).

With the recent development of the thermionic tube all other forms of asymmetric conductor (rectifier) have given place to it or are rapidly doing so, and the constancy and determinate nature of the thermionic conductor, as compared with (say) electrolytic or crystal detectors, are a great stimulus towards the elucidation of the mathematical theory of rectification. On the other hand, recent developments have complicated and widened the investigation in several ways. The high-frequency alternating E.M.F. due to the signal is now never applied alone to the rectifier circuit, but always added to a steady E.M.F.; it cannot always be treated as indefinitely small (as when relay replaces telephone reception); it is usually not applied in the circuit of the indicating instrument, but in an associated circuit thermionically related with it (as in triode rectification); and, finally, the circuits are sometimes such that the rectified current at any instant does not depend only on the signal at that instant but also upon the course of the signal in past instants (as in cumulative grid rectification).

Since it must cover so many different arrangements and conditions, the complete theory of rectification as at present practised in wireless receivers is somewhat extensive. It does not seem to have been fully worked out in previous publications, and, more especially, such theory as has been given has not been adequately verified experimentally.

2. Scope of Paper.

In the present paper, the performances of the various triode rectifying arrangements have been calculated fairly exhaustively in terms of the parameters of the triode as exhibited in its static characteristic curves. The paper does not deal with the physics of the triode upon which the characteristics depend; but the shapes of these characteristics are to some extent analysed, and formulæ are developed from which the rectifying performances of any given triode can be calculated and the best circuit values determined. The theoretical results obtained are in all cases illustrated by numerical calculations for a single typical pattern of triode, the well-known "R" triode used so largely during and since the war; and they have been experimentally checked in the more fundamental cases by precise measurements with signal E.M.F.'s of low frequency (90 periods per sec.).

The operative E.M.F. applied to the rectifier depends

on the local heterodyne oscillator, when there is one, as well as on the far-off transmitter. Accordingly, the types of signal dealt with are classified as :

(S1). Sustained C.W. (continuous wave) signal E.M.F. $e = a \sin pt$;
(S2). The same with added heterodyne E.M.F. $b \sin qt$;
(S3). Damped train E.M.F. $e = ae^{-mt} \sin pt$.

The rectifier arrangements investigated with these signals are classified as follows :

(R1). Rectification by curvature of anode characteristic, called " anode rectification " ;
(R2). Rectification by curvature of grid characteristic, called " grid rectification " ;
(R3). The same with grid condenser, called " cumulative grid rectification."

In all cases the signal is supposed to be applied in the grid-filament circuit of a triode, and in all except one introductory case the indicating instrument (e.g. telephone or relay) is supposed to be inserted in the anode circuit ; the operative current in it, called the " signal current," is the change of mean anode current consequent on the arrival of the signal. In the case of heterodyne reception, where the high-frequency mean anode current fluctuates at an acoustic frequency, the term " signal current " is taken to connote the range of the acoustic fluctuations of the mean. Making use of the above S and R classification, the cases investigated are shown in Table 1.

TABLE 1.

Case	Strength of signal	Strength of heterodyne	Dealt with particularly in Sections
S1, R1 ..	General and	Nil	5, 6
S1, R2 ..	weak		
S1, R1	Strong	Nil	7
S1, R3	Weak and moderate	Nil	8, 9
S1, R3	Strong	Nil	9
S2, R1	Weak and moderate	Moderate	11
S2, R1	General	Strong	12
S2, R3	Weak	Weak	13
S2, R3	General	Strong	13
S3, R1	Moderate	Nil	15

The investigations refer, in the first instance, to circuits in which the signal currents do not produce sensible changes of anode potential, although when indicating apparatus of sensible impedance is used, change of potential must occur. In Section 16 the correction required on account of the change of anode potential is calculated for the cases of sustained continuous-wave signal (S1 and S2).

3. The " R " Triode.

Typical static characteristic curves for the triode used in most of the measurements, from which slopes and higher differentials can be calculated, are given in Figs. 1 and 2. This triode was in no way a peculiar one, and although different specimens of the same pattern will obviously have somewhat different characteristic curves, it was found that a number of specimens of the same make (" Osram ") exhibited curves of nearly identical shape. It may be assumed that calculations for this particular specimen will approximately hold for any other specimen of the same pattern ; that the formulæ developed will equally apply to other patterns of high-vacuum triode, the relevant values of the parameters being taken ; and

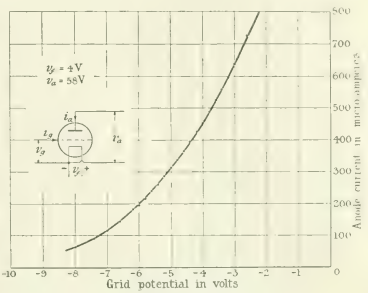


FIG. 1.—Anode-current/grid-potential curve for " R " triode.

that if the formulæ are found to agree with observation in the case of several specimens, there is every probability that they are generally true.

4. Experimental Method.*

Provided that within the triode there is nothing in the nature of sluggishness or temperature hysteresis making itself perceptible during the high-frequency changes occurring in actual use—which is probably the case in high-vacuum receiving tubes—it does not matter whether the predictions from the static characteristic as to behaviour with alternating current are put to the test at 50 or a million periods per second. The use of a commercial a.c. power supply offers great advantages in respect of ease and accuracy of adjustment and measurement of the applied signal E.M.F. Consequently the town supply at 90 periods was utilized in these tests, any desired low voltage being obtained by means of step-down transformers and potential dividers of resistance form.

In most rectifier measurements the steady non-signal current is vastly larger than the changes in it constituting the rectified current or signal current, and it is therefore necessary to employ a balance method of measuring the signal current. This was done

* The tests were carried out in the Engineering Laboratory, Cambridge, with facilities put at our disposal by Prof. C. E. Inglis.

very simply in the way indicated in Fig. 3, which shows the typical circuit for measuring the rectified current in an S1, R1 arrangement (see Table 1). The potential divider P is set to give zero deflection of the galvanometer G (sometimes a "Unipivot" micro-ammeter and sometimes a reflecting galvanometer) in the absence of the signal; then in the presence of the signal the galvanometer reads an easily calculated fraction of the change of anode current.

Then $v = v_0 + e$,

and $i = f(v_0) + ef'(v_0) + \frac{e^2}{2!}f''(v_0) + \frac{e^3}{3!}f'''(v_0) + \ldots$

Let $e = a\sin pt + a_3\sin 3pt + a_5\sin 5pt + \ldots$

then $i = f(v_0) + (a\sin pt + a_3\sin 3pt + a_5\sin 5pt + \ldots)f'(v_0)$

$+ \frac{1}{2!}(a\sin pt + a_3\sin 3pt + a_5\sin 5pt + \ldots)^2 f''(v_0) + \ldots$

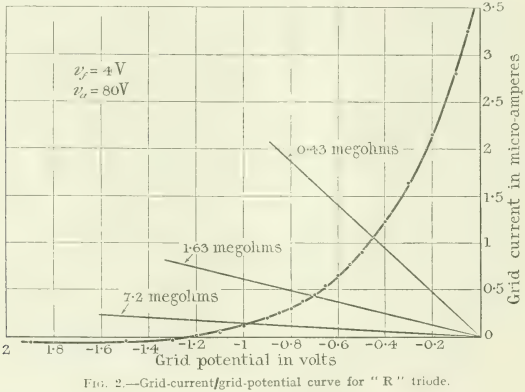


FIG. 2.—Grid-current/grid-potential curve for "R" triode.

By this means small changes such as 5μA are measured with ease, and with care changes such as $0{\cdot}25\mu$A can be determined to within 10 per cent. Indeed, actual steady wireless signals (long dash) of (say) one-tenth of a volt or less can be conveniently

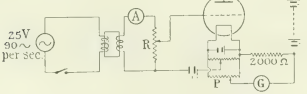


FIG. 3.

measured by means of the rectified current in this way.

5. Theory of Rectification of Sustained C.W. Signals by an Asymmetric Conductor.

The theory is well known, but may be stated briefly as follows (Fig. 4): Let the asymmetric conductor (the rectifier) have a curved characteristic of the general form $i = f(v)$, and suppose, moreover, that it is possible to represent this function by an infinite series.

If change of mean current due to the signal e is I_r,

$$I_r = \frac{(a^2 + a_3^2 + a_5^2 + \ldots)}{4} f''(v_0) + \frac{(a^4 + a_3^4 + a_5^4 + \ldots + 2a^2a_3^2 + \ldots)}{64} f''''(v_0)$$

Now suppose that the values of a, a_3, a_5, etc., and $f''''(v_0)$, etc., are such that

$$\frac{(a^4 + a_3^4 + a_5^4 + \ldots + 2a^2a_3^2 + \ldots)}{16} f''''(v_0)$$

is small compared with $(a^2 + a_3^2 + a_5^2 + \ldots)f''(v_0)$; then

$$I_r = \frac{\text{mean-square } e}{2} f''(v_0) \equiv \frac{\mathcal{E}^2}{2}\frac{d^2}{dv_0^2} \quad . \quad . \quad (1)$$

Hence, unless the characteristic curve is such that d^4i/dv^4 is very large, the rectified current from a very weak signal is proportional to the rate of change of the slope of the characteristic, and to the square of the strength of the signal P.D., whether the latter contains harmonics or not—a point not always noticed.

This theory is, of course, applicable to a diode; or to a triode used as a diode by omitting to utilize either grid or anode; or to a triode in which the

signal is applied in the grid circuit and the signal current is in the anode circuit. In the last case, the relevant i, v characteristic is that between anode current and grid potential for constant anode potential, as in Fig. 1.

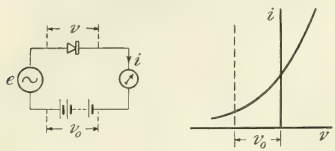


FIG. 4.

6. EXPERIMENTAL VERIFICATION OF SECTION 5.

In Figs. 5 (*a*), 5 (*b*), 5 (*c*) are shown the curves for anode rectification relating observed rectified current with the square of the virtual value of the signal E.M.F.* It is seen that they are all straight lines so long as the applied E.M.F. does not exceed about 1·3 volts (R.M.S.). At greater signal strengths the observed values lie below this straight line: this agrees with the fact, shown by the static characteristic, that d^4i_a/dv_g^4 though small is not zero; it has a negative value, which makes the a^4 term of the expansion in Section 5 above increasingly significant as the signal increases in strength. On each curve the observed slope of the straight line is marked, and below it, for comparison, the calculated slope measured from the derived static characteristics.

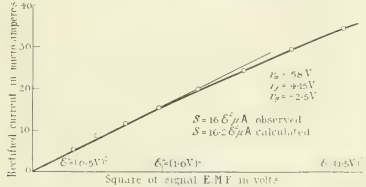


FIG. 5 (*a*).—Anode rectification.

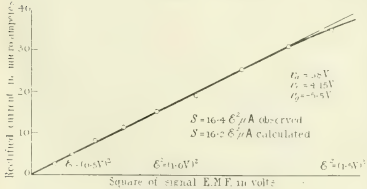


FIG. 5 (*b*).—Anode rectification.

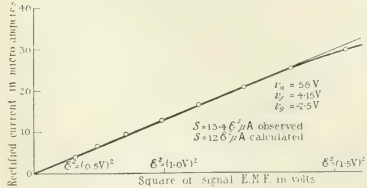


FIG. 5 (*c*).—Anode rectification.

Fig. 6 shows how the rectified current from a 1-volt signal depends upon the mean grid potential. Over a wide range it is almost independent of mean grid potential, and the rectified current is nearly $16\mathcal{E}^2$ micro-amperes. Three other "R" triodes of the same make tested in this way gave rectified currents differing by not more than ± 5 per cent from this figure, and consequently the relation $S = 16\mathcal{E}^2$ micro-amperes may be taken with fair accuracy to represent the anode rectification curve of any "R" triode.

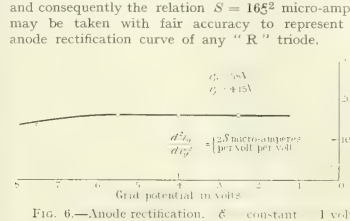


FIG. 6.—Anode rectification. $\mathcal{E}$ = constant = 1 volt (R.M.S.).

Analysis of static characteristic by means of these results.—As the mean grid potential is varied between − 2·5 volts and − 5·5 volts the value of d^2i_a/dv_g^2 is seen to lie between 32 and 33 micro-amperes per volt per volt; also when the applied signal E.M.F. is 1·5 volts (R.M.S.) the observed rectified current is not more than 3 per cent below the value given by the expression $S = 16\mathcal{E}^2$. Now the expansion in Section 5 will allow us, with the help of these numerical values, to calculate the approximate values of d^4i_a/dv_g^4. For

$$i = \mathcal{E}^2\frac{d^2i_a}{2\,dv_g^2}\left(1 + \frac{\mathcal{E}^2}{8}\cdot\frac{d^4i_a}{dv_g^4}\Big/\frac{d^2i_a}{dv_g^2}\right) + \ldots,$$

consequently

$$\frac{(1\cdot5)^2 d^4i_a/dv_g^4}{8\,d^2i_a/dv_g^2} = 0\cdot1 \text{ to } 0\cdot2,$$

that is,

$$\frac{d^4i_a}{dv_g^4} = 0\cdot1\frac{d^2i_a}{dv_g^2}$$

Also Fig. 6 has shown that over a very large range d^2i_a/dv_g^2 varies by only about 3 per cent. Hence the anode current characteristic of an "R" triode is evidently very nearly a parabola. If, therefore, it is desired to calculate the instantaneous anode current, so long as the mean grid potential gives a state point on the characteristic suitable for rectification, the anode characteristic may be taken as given by the equation

$$i_a = \alpha + \beta v_g + \gamma v_g^2$$

* Throughout the paper E.M.F.'s are quoted in volts.

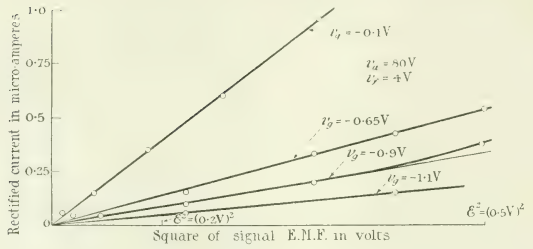


FIG. 7 (*a*).

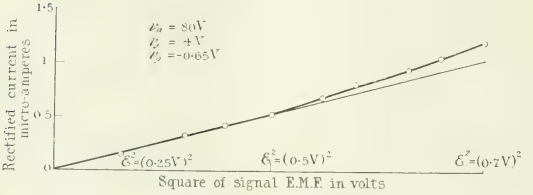


FIG. 7 (*b*).—Extension of one curve in Fig. 7 (*a*).

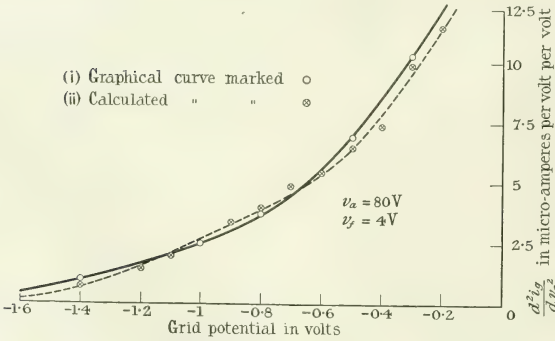


FIG. 8.—Curves of d^2i_a/dv_g^2 (i) derived graphically from static characteristic, and (ii) calculated from formula $S = \frac{1}{2}\mathcal{E}^2(d^2i_a/dv_g^2)$ with $\mathcal{E}$ = constant = 0·38 V (R.M.S.).

This is a fact that may be of use in analysing the behaviour of a triode in various arrangements, and is actually applied later in the paper in the examination of reception with weak heterodyne (Section 11).

Rectification by curvature of grid current characteristic.—In this case the rectified current is not very much smaller than the mean grid current, and in measuring the rectified current it is not necessary to resort to the balance method of Fig. 3.

In Fig. 7 observed rectified current is plotted against the square of the applied signal P.D. with four different mean grid potentials. It is seen from these graphs that if the signal much exceeds about 0·5 volt (R.M.S.) the terms involving $\delta^4 . d^4i_a/dv_g^4$, etc., assume importance; but that if the signal is less than 0·5 volt the rectified current varies very closely as the square of the signal strength. If, therefore, a constant weak signal is applied and the rectified current is measured with various mean grid potentials, it should be possible to deduce the value of d^2i_a/dv_g^2 for any mean grid potential. Fig. 8 shows the curve connecting v_g and d^2i_a/dv_g^2 obtained experimentally in this way, using a constant signal of 0·38 volt (R.M.S.), together with the same curve derived graphically from the static characteristic. It is seen that the two curves very nearly coincide—a striking confirmation of the adequacy of the theoretical analysis of this type of rectification. It follows that the grid current curve does not, like the anode current curve, approximate to a parabola, but is in fact much more nearly an exponential curve.

7. Limiting Condition when Signal is Indefinitely Strong.

The case of a very strong signal (much more than one volt) is met with in relay reception; but it is of interest more especially with reference to ordinary heterodyne reception (discussed in Section 12). Even if it were feasible to determine accurately the higher differential coefficients, and so calculate the rectified current from the expansion in Section 5, there would not be much practical interest in doing so here. For with very large alternating grid potential the rectification tends to become "perfect"; that is to say, that whereas during the positive half-cycle large currents flow through the detector, during the negative half the currents are negligible in comparison.

If the maximum value of the alternating P.D. applied to the detector, now assumed to be sinusoidal, is E, the mean value during a half-wave is $(2/\pi)E = (2\sqrt{2}/\pi)\delta$, where δ is the R.M.S. value. If E is so large that we can take the characteristic as sensibly a straight line over the great majority of the positive half-period, then the mean current during that half-period tends towards $(2\sqrt{2}/\pi)\delta . di/dv$, and the mean current over the whole period (or any number of whole periods) is approximately $(\sqrt{2}/\pi)\delta . di_a/dv_g = 0·45\delta . di_a/dv_g$.

Complete rectified current curve for anode rectification.—We have seen that the rectified current curve starts as the parabola $I_r = 16\delta^2$ micro-amperes (Section 6), and must, if saturation is not approached, finally become asymptotic to the line

$$I_r = 0·45\delta . di_a/dv_g$$

Fig. 9 shows the observed curve for an "R" triode in which $di_a/dv_g = 200$ micro-amperes per volt, together with the straight line $I_r = 0·45\delta . di_a/dv_g = 90\delta$ micro-amperes, which the observed curve approaches as δ increases.

The same argument applies to grid rectification with large applied signal. But such rectification cannot become apparent in the anode circuit without the insertion into the grid circuit of a condenser or resistance, or both. Large rectified grid currents with fixed mean

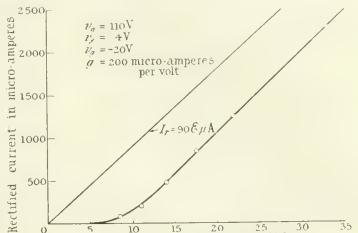


Fig. 9.—Anode rectification.

grid potential are consequently without practical interest; and no experimental curves have been taken for this case.

8. Cumulative Grid Rectification.

In the method which goes under this name the grid is partially insulated by the insertion of a "leaky" condenser, as in Fig. 10. The signal current is now the change of mean anode current accompanying change

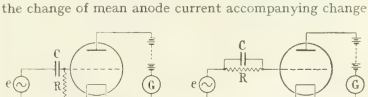


Fig. 10.

of mean grid potential due to rectification in the grid circuit. The method is well known, but its quantitative theory has not been clearly set out. It is best approached graphically, as the significance of the necessary approximations made is then more clearly appreciated. The two methods of connection shown in the figure are electrically equivalent, and in each case the steady non-signal grid potential is found from the simultaneous solution of the equations

$$i_g = f(v_g) \quad \text{and} \quad i_g = -v_g/R$$

The shape of the grid current curve $f(v_g)$ is such that its analytical treatment is impracticable, and the solution can best be found graphically as shown in **Fig. 11**. The steady grid potential is given by OA,

the abscissa of the point of intersection B of the grid and resistance characteristics.

The function of the condenser in the two methods of connection is slightly different. In Fig. 10 (*a*) its function is to interrupt the circuit RC*e* so far as steady currents are concerned ; and C is supposed to be so large that the alternating current flowing through it produces no sensible alternating P.D. across it. In other words the full signal E.M.F. may be considered

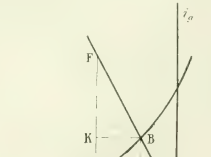


FIG. 11.—Cumulative grid rectification.

to be applied between grid and filament. In Fig. 10 (*b*) the function of C is to provide a high-frequency shunt across R, so that again the full signal E.M.F. may be considered to be applied between grid and filament. The alternating potential of the grid makes the mean grid current increase ; and since, in either method of connection, this increased current must flow through R, the mean grid potential is thereby lowered. The

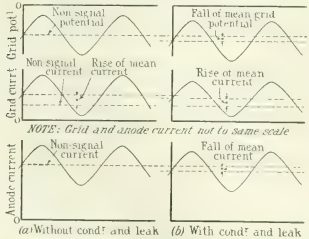


FIG. 12.

accompanying reduction of mean anode current is utilized to operate an indicating instrument.

The effect in the anode circuit of the events in the grid circuit are well exhibited in Fig. 12. Fig. 12 (*a*) depicts grid potential, grid current and anode current in the absence of the condenser and resistance : the signal produces no change of mean grid potential or anode current. Fig. 21 (*b*) depicts the same quantities, when the steady state has been reached, with the cumulative grid method of connection : there is now a decrease of mean grid potential ; still an increase in mean grid current [though the increase is less than in Fig. 12 (*a*)] ; and a decrease in mean anode current. All these changes in mean values can easily be found graphically from Fig. 11 as follows. Suppose that the E.M.F. applied to the grid produces a rectified current I_r. Find a point F on the line OB such that the intercept FE of the ordinate FD between the resistance line and the grid curve is equal to I_r on the scale of the diagram. The new mean grid current is DF, which may be analysed into two parts, FE called the rectified current, and FD the steady grid current associated with the new mean grid potential OD. The fall of mean grid potential is evidently DA, and hence the fall of mean anode current is $\mathrm{DA} \times di_a/dv_g \equiv g\,.\,\mathrm{DA}$. The increase in mean grid current shown in Fig. 12 (*a*) is FE, and in Fig. 12 (*b*) is the smaller amount FK.

The above graphical method is applicable with signals of any strength, and may be used for calculating by trial and error the signal current for any given signal. With weak signals, on the other hand, an approximate formula for the signal current will now be derived. We have found theoretically, and verified experimentally, that with constant mean grid potential the grid rectified current is very closely $\frac{1}{2}\mathcal{E}^2\,.\,d^2i_g/dv_g^2$ provided that $\mathcal{E}$ does not exceed about 0·5 volt. Hence if DA (Fig. 11) is small so that the value of d^2i_g/dv_g^2 at E does not much differ from its value at B, we can say that $\mathrm{FE} = \frac{1}{2}\mathcal{E}^2\,.\,d^2i_g/dv_g^2$, where d^2i_g/dv_g^2 is the value of the second derived function at B, i.e. at the state point, determined by R, before the signal arrived. At B draw a tangent to the grid curve, and let it cut FD at G and make an angle ψ with the horizontal. Suppose that DA is so small that the tangent departs very little from the curve between A and D and we can take GF as sensibly equal to EF. Then we have

$$\mathrm{DG} = \mathrm{DF} - \mathrm{FG}$$

$$= \frac{1}{R}\,.\,\mathrm{DO} - \mathrm{EF}$$

$$= \frac{1}{R}\,.\,\mathrm{DO} - \frac{\mathcal{E}^2}{2}\frac{d^2i_g}{dv_g^2}$$

Now $$\mathrm{DA} = (\mathrm{BA} - \mathrm{DG})\cot\psi$$

$$\therefore \mathrm{DA} = \left(\frac{1}{R}\,.\,\mathrm{AO} - \frac{1}{R}\,.\,\mathrm{DO} + \frac{\mathcal{E}^2}{2}\frac{d^2i_g}{dv_g^2}\right)\cot\psi$$

$$= \left(-\frac{1}{R}\,.\,\mathrm{DA} + \frac{\mathcal{E}^2}{2}\frac{d^2i_g}{dv_g^2}\right)\cot\psi$$

that is, $$\mathrm{DA}\left(\frac{1}{R} + \tan\psi\right) = \frac{\mathcal{E}^2}{2}\frac{d^2i_g}{dv_g^2}$$

$$\therefore \mathrm{DA} = \frac{\frac{\mathcal{E}^2}{2}\frac{d^2i_g}{dv_g^2}}{\frac{1}{R} + \frac{di_g}{dv_g}}$$

This gives signal current

$$S = g\,.\,\mathrm{DA} = \frac{\frac{\mathcal{E}^2}{2}\frac{d^2i_g}{dv_g^2}}{\frac{1}{R} + \frac{di_g}{dv_g}}\,.\,\frac{di_a}{dv_g} \quad . \quad . \quad . \quad (2)$$

This formula is not of much service in calculating the signal current from any except extremely weak signals, because we do not know what value to attach to d^2i_g/dv_g^2 until we know the rectified current. The appropriate value is the value at the undetermined point E, not at the non-signal state point B. With very weak signals disregard of any difference between these two values is no doubt a second-order inaccuracy; but with a signal of 0·5 volt (R.M.S.), when $R = 7{\cdot}2$ megohms the observed signal current (Fig. 15) indicates that the grid potential has fallen by 0·25 volt; and reference to Figs. 8 and 2 shows that this has reduced d^2i_g/dv_g^2 by about 40 per cent.

If we suppose that $\mathcal{E}$ is sufficiently small to permit us to use the non-signal state point value of d^2i_g/dv_g^2, the error introduced by our approximation of ignoring EG in FG = FE + EG can be reduced by putting

$$\mathrm{EG} = \tfrac{1}{2}(\mathrm{DA}) \times \frac{d^2i_g}{dv_g^2}$$

This changes formula (2) into the more accurate formula

$$S = \frac{\mathcal{E}^2 \dfrac{d^2i_g}{dv_g^2}}{\dfrac{1}{R} + \dfrac{di_g}{dv_g}} \cdot \frac{1}{2}\left\{1 + \frac{\dfrac{\mathcal{E}^2}{2}\left(\dfrac{d^2i_g}{dv_g^2}\right)^2}{\left(\dfrac{1}{R} + \dfrac{di_g}{dv_g}\right)^2}\right\} \cdot \frac{di_a}{dv_g} \quad . \quad (3)$$

9. Experimental Verification of Section 8.

As an example of the graphical method of predicting the signal current, let us take the following numerical case. When using a grid leak of 0·43 megohm, a signal E.M.F. of 0·38 volt (R.M.S.) was observed to produce a signal current of 21 μA. Fig. 2 shows that with this value of grid leak the non-signal grid potential is 0·47 volt. The experiments from which Fig. 8 is produced showed that if $v_g = -0{\cdot}47$ volt an applied E.M.F. of 0·38 volt (R.M.S.) produces a rectified current of 0·5 μA. Fig. 2, again, shows that this increase of grid current brings the grid potential to $-0{\cdot}57$ volt, a reduction of 0·1 volt from the non-signal value. In this triode with the anode potential in use $di_a/dv_g = 290$ micro-amperes per volt, so that the signal current caused by a change of grid potential of 0·1 volt is 29 μA. This is some 30 per cent above the observed value, 21 μA. If, however, proceeding by trial and error, we now guess that the grid potential would be reduced to (say) $-0{\cdot}55$ volt instead of $-0{\cdot}57$, the rectified current shown by Fig. 8 would be only 0·45 μA instead of 0·51 μA. Fig. 2 shows that this increase of 0·45 μA in grid current would lower the grid potential almost exactly to $-0{\cdot}55$ volt, a decrease due to the signal of 0·8 volt; and the consequent signal current would be 23 μA. The agreement between this and the observed 21 μA is no doubt sufficiently close to verify the above theory of the action of the rectifier with fairly strong signals.

Using the balance method of Section 4 with a highly sensitive galvanometer capable of measuring $\frac{1}{50}$ μA, it is possible to observe the signal current in the anode circuit produced by a signal on the grid of only 0·01 volt.* Figs. 13 and 14 show the observed signal current with signal E.M.F.'s up to 0·12 volt (R.M.S.); and the dotted curves in the same figure show the values calculated from formula (2) above by using the values of d^2i_g/dv_g^2, etc., found graphically from the triode characteristics. The agreement is very close, and shows that the expressions (2) and (3) are sensibly accurate as long as E does not exceed 0·1 volt.

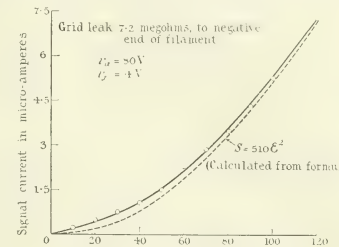


Fig. 13.—Cumulative grid rectification.

The curve of Fig. 15 shows signal current plotted against applied E.M.F. for a grid leak of 7·2 megohms connected to the negative end of the filament. The applied signals are fairly strong, so that the curves do not agree with those given by either of the foregoing formulæ (2) and (3), for the reasons already stated. It will also be noticed that the signal current increases less rapidly than as the square of the applied E.M.F.

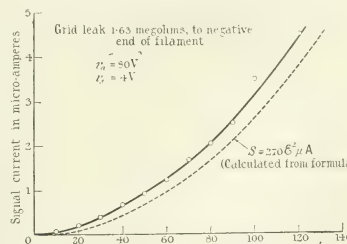


Fig. 14.—Cumulative grid rectification.

Choice of grid leak and state point on grid characteristic.—With any value of grid leak resistance any desired state point may be attained by connecting the outer end of the grid leak to a point at suitable potential, positive or negative, with respect to the

* It may be remarked in passing that we are then observing changes in anode current of one part in 20 or 30 thousand—a testimony to the convenience of the balance arrangement employed.

negative end of the filament. For any assigned state point, the expression $\frac{d^2i_g/dv_g^2}{1/R + di_g/dv_g}$, to which we have seen the signal current is proportional, can be increased

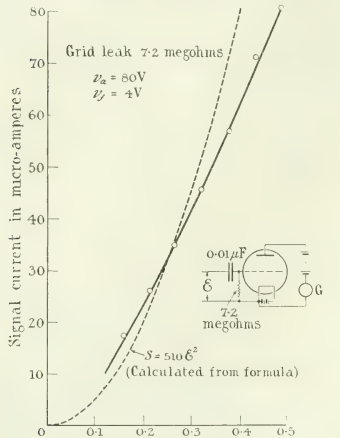


FIG. 15.—Cumulative grid rectification.

by merely increasing R; and since also the ratio $(d^2i_g/dv_g^2) \div (di_g/dv_g)$ becomes ever greater as the grid potential v_g is lowered, it is best to choose a large value

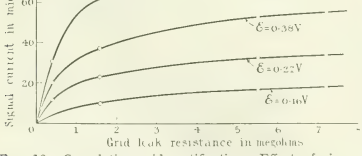


FIG. 16.—Cumulative grid rectification. Effect of size of grid leak on signal current.

for R, and to connect the outer end of the leak to the negative in preference to the positive end of the filament.

Fig. 16 shows the observed relation between signal current and grid leak resistance R for four strengths of constant applied signal: the importance of keeping R not less than (say) 5 megohms is clearly shown. Fig. 17 shows the relation, with a large value of R and for a constant applied signal, between signal current and the non-signal grid potential. In this case it may be seen that if the leak is connected to a point at a potential even as high as + 20 volts, the signal current is only some 25 per cent less than when it is connected to the negative end of the filament. Thus the important point is to make R large rather than select it to arrive

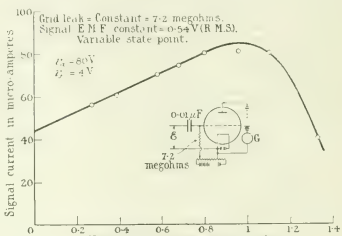


FIG. 17.—Cumulative grid rectification.

at any particular state point. In fact it matters little whether the leak is connected to the positive or negative end of the filament, provided only that R is large, say at least 5 megohms.

Choice of grid condenser.—It has already been pointed out that the function of the condenser is that of a high-frequency shunt. In order to keep the time-constant of the circuit as low as possible, the capacity should be kept as small as is compatible with its efficient

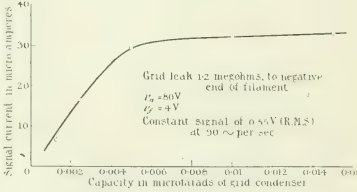

Grid leak 1·2 megohms, to negative end of filament
v_a = 80V
v_f = 4V
Constant signal of 0·55V (R.M.S.) at 90 ~ per sec
Signal current in micro amperes
Capacity in microfarads of grid condenser

FIG. 18.—Cumulative grid rectification. Effect of size of grid condenser.

action as a shunt. Fig. 18 shows observed values of signal current, produced by a constant signal of 0·55 volt (R.M.S.) at 90 periods per sec., plotted against capacity of grid condenser. It is seen that at this frequency the capacity can be reduced to 0·01 μF without sensibly reducing the signal current. The capacity of a like impedance at a wireless frequency of (say) 10^5 periods per sec. is about 1 $\mu\mu$F. If, however, the grid condenser were actually reduced to so tiny a value, it would be less than the internal capacity of the triode; and Fig. 18 refers only to the case of a grid condenser

great in comparison with the internal capacity. No doubt the condenser may safely be reduced to (say) 50 $\mu\mu$F; and as the equivalent resistance of grid and leak in parallel is about 1·5 megohms, the time-constant of the circuit can be reduced to about 75 micro-seconds. With these values, if signals of 3 000 metres wave-length are being received, the signal current will attain the value given by formula (2) in about 40 periods.

In the circuit of Fig. 10 (*b*) it is possible to omit the condenser altogether; and formula (2) may be used to calculate the signal current in this case. A signal $\mathcal{E}$, applied between the outer end of R and the filament, produces a potential difference $\mathcal{E}'$ between

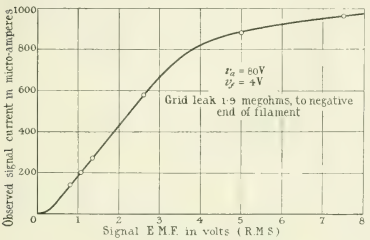


FIG. 19.—Cumulative grid rectification.

grid and filament, which, if we can neglect the internal capacity of the grid, is

$$\mathcal{E}' = \mathcal{E} \cdot \frac{r}{R + r} \quad \text{where} \quad r \equiv 1 \Big/ \frac{di_g}{dv_g}$$

The signal current is then

$$S = \frac{\mathcal{E}'^2}{2} \cdot \frac{R\,r}{R + r} \cdot \frac{d^2 i_g}{dv_g^2} \cdot g$$
$$= \frac{\mathcal{E}^2}{2} \cdot \frac{Rr^2}{(R + r)^3} \cdot \frac{d^2 i_g}{dv_g^2} \cdot g$$

This is easily shown to be a maximum for choice of R when $R = \frac{1}{2}r$, giving an optimum

$$S = \frac{4}{27} \cdot \frac{\mathcal{E}^2}{2} \frac{d^2 i_g}{dv_g^2} \Big/ \frac{di_g}{dv_g} \cdot g$$

Taking 2·5 as the appropriate value of $(d^2 i_g / dv_g^2) \div (di_g / dv_g)$ in the "R" triode, we get

$S = 55\mathcal{E}^2$ micro-amperes if $g = 300$ micro-amperes per volt.

Cumulative grid rectification with very strong signals.—We have seen that the rectified current curve is a parabola for signals not exceeding 0·1 volt. Fig. 19 shows that when the signal lies between 0·25 volt and 3 volts the curve is found to be approximately the straight line $S = 210\mathcal{E}$ micro-amperes; and above 3 volts the curve finally becomes asymptotic to the line $S = 1\,000$ micro-amperes. The straight portion is easily accounted for as due to "perfect" rectification; and the final convex portion is explained by the two facts (i) that as the mean grid potential becomes more and more negative, the grid current flows for a decreasing part instead of the whole of the positive half-cycle, and (ii) increasing negative grid potentials tend towards the lower curved portion of the anode current characteristic and so again lessen the signal current.

10. Comparison between Anode and Cumulative Grid Rectification.

The signal currents produced by a sustained signal $\mathcal{E}$ have been found to be given, according to the value of $\mathcal{E}$, approximately by the several formulæ collected in Table 2.

TABLE 2.

Strength of signal $\mathcal{E}$ volts (R.M.S.)	Signal current in micro-amperes, with: Anode rectification	Signal current in micro-amperes, with: Cum. grid rectn.	Ratio
$<0{\cdot}1$	$16\mathcal{E}^2$	$500\mathcal{E}^2$	30
$0{\cdot}25$ to 2	$16\mathcal{E}^2$	$210\mathcal{E}$	$6\frac{1}{2}$ when $\mathcal{E}=2$
>10	$100\mathcal{E} - 800$	1 000	1 when $\mathcal{E}=20$

Thus cumulative grid rectification is for weak signals some 30 times, for moderate signals some $6\frac{1}{2}$ times, and for strong signals about once, as sensitive as anode rectification. Such marked superiority as 20 or 30 times is likely to be questioned by those who have used both rectifying arrangements in wireless receivers, and some explanation of this apparent discrepancy between theory and practice is offered below.

First, it is to be remembered that the comparison we have drawn is for continuous-wave working without heterodyne; so that although with weak signals the signal current may indeed be some 20 or 30 times as great with cumulative grid as with anode rectification, there is no means of making this signal current declare itself. The current is too weak to operate a relay, and cannot affect a telephone in the absence of a heterodyne. With stronger signals, or with any signals in the presence of a heterodyne (as will be seen in Section 14), the superiority is reduced from 30 to a much smaller figure.

Secondly, Table 2 is not directly applicable to spark signals; for the cumulative grid rectifier, as its name implies, has a time-constant, whereas the anode rectifier has none. Unless the time-constant CR of the grid condenser and its leak is negligibly small in comparison with the duration of the signal train—and previous remarks on this time-constant show that with short waves it is not—the grid cannot reach as low a potential as it would finally reach if the P.D. were sustained in amplitude: and it is this final value which is given in Table 2. It is shown in Section 13 that this effect

may not be very considerable with heterodyne reception of continuous-wave signals; but its importance in the case of spark signals is not easily estimated. In whatever degree this occurs, however, the effect must cause the superiority to fall below the ratios shown in Table 2.

It has been seen that the grid rectifier obtained by omitting the grid condenser, and therefore without time-constant, can with optimum adjustment give a signal current $S = 55\xi^2$ micro-amperes, as compared with the $S = 16\xi^2$ micro-amperes given by an anode rectifier—a superiority of $3\frac{1}{2}$ times. Perhaps these can be taken as approximating to the conditions obtaining in the cumulative grid rectifier with highly damped short waves when the grid condenser is much too large. This leads to $3\frac{1}{2}$ as a lower limit of cumulative grid superiority with weak spark signals. Rough comparison tests have been made with spark signals

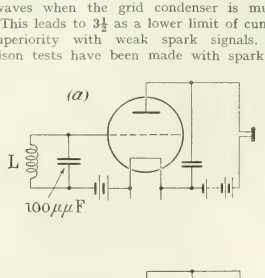


FIG. 20.

from the Eiffel Tower, the two rectifier arrangements being interchangeable by press keys. It was observed that the cumulative grid rectifier was quite definitely superior to the anode rectifier, though not very markedly.

A third reason why the ratios of Table 2 are not substantiated in wireless practice lies in the damping which is necessarily produced in the cumulative grid but not in the anode rectifier arrangement. Owing to this damping, any given signal E.M.F. in the receiving antenna cannot be made to produce as large a signal P.D. on the grid in the former as in the latter arrangement. The extent to which this fact is felt depends on various factors, but that it can be large is easily seen by considering a reasonable numerical example. We will assume that a certain power, say 10^{-10} watt, is fed into the oscillatory circuit with each arrangement;* that the wave-length is 3 000 metres; that the decrement of the oscillatory circuit alone is 0·02; and that for practical reasons the capacity of the condenser cannot be reduced below 100 μμF and is given that value in both cases. With anode rectification [Fig. 20 (*a*)], with the grid at sufficiently low a potential as to produce negligible damping, the signal P.D. across the coil L would be 0·016 volt. With cumulative grid rectification [Fig. 20 (*b*)], if the total leak resistance is (say) $\frac{1}{2}$ megohm, the decrement of the circuit rises to 0·12, and the same signal power fed in produces across L a P.D. of only 0·0064 volt. The ratio of signal currents in the telephone would therefore be not the 30 of Table 2, but $30 \times (0{\cdot}0064/0{\cdot}016)^2 = 5$. It is to be noticed that this disability of cumulative grid rectification due to damping introduced by the rectifier is obviated if the rectifier is connected across the resistance in the anode circuit of an amplifying triode inserted between the oscillatory circuit and the rectifier.

* In so far as this assumption is untrue, it unduly favours cumulative grid rectification.

11. Anode Rectification with Heterodyne of Moderate Strength.

It has been shown (Section 6) that the foot of the anode-current/grid-potential characteristic may be expressed by the equation

$$i_a = \alpha + \beta v_g + \gamma v_g^2$$

the rate of change of slope, d^2i_a/dv_g^2, being approximately a constant, 2γ. With the signal potential difference $e = a \sin pt$ and the superposed heterodyne potential difference $b \sin qt$ we have

$$v = a \sin pt + b \sin qt$$

Hence

$$\begin{aligned} i_a &= \alpha + \beta(a \sin pt + b \sin qt) \\ &\quad + \gamma(a^2 \sin^2 pt + b^2 \sin^2 qt + 2ab \sin pt \sin qt) \\ &= \alpha + \beta(a \sin pt + b \sin qt) \\ &\quad + \frac{\gamma a^2}{2}(1 - \cos 2pt) + \frac{\gamma b^2}{2}(1 - \cos 2qt) \\ &\quad + \gamma ab\{\cos(p - q)t - \cos(p + q)t\} \end{aligned}$$

The effects on the anode circuit of the signal e accordingly are:

(i) To increase the mean current by $\frac{1}{2}\gamma b^2$;
(ii) To introduce high-frequency currents of frequencies corresponding to $2q$ and $(p + q)$; and
(iii) To introduce a low-frequency current

$$\gamma ab \cos(p - q)t$$

Item (iii) is responsible for the acoustic effect in the telephone inserted in the anode circuit, and is accordingly here termed the signal current. The total range, $2\gamma ab$, of this acoustic fluctuation is called the magnitude of the signal current.

The signal current, then, is of magnitude

$$2\gamma ab = ab\frac{d^2i_a}{dv_g^2} = \sqrt{2}\xi b\frac{d^2i_a}{dv_g^2}$$

The same result may be reached as follows. The amplitude of P.D. across the rectifier varies between $(b + a)$ and $(b - a)$ at an acoustic frequency small compared with the wireless frequency $p/2\pi$. Hence

(Section 5) the high-frequency mean of the anode current ranges from

$$\tfrac{1}{4}(b-a)^2 \cdot d^2i_a/dv_g^2 \quad \text{to} \quad \tfrac{1}{4}(b \quad a)^2 \cdot d^2i_a/dv_g^2$$

The signal current is therefore

$$\tfrac{1}{4}\,d^2i_a \cdot (b-a)^2 - (b \quad a)^2 \cdot \quad ab\,\frac{d^2i_a}{dv_g^2} \text{ as before.}$$

But the formulæ

$$\text{mean } i_a = \tfrac{1}{4}(b-a)^2 \cdot d^2i_a/dv_g^2$$

are applicable only for values of $\mathcal{E} = (b+a)/\sqrt{2}$ up to about 2 volts, and over this range for an " R " triode $d^2i_a/dv_g^2 =$ constant $= 32$ micro-amperes per volt per volt. Hence the best signal current with a weak signal (namely, when $b + a = b$ is adjusted to be about $2\sqrt{2}$ volt) is

$$S = 128\mathcal{E} \text{ micro-amperes.}$$

12. Anode Rectification with Very Strong Heterodyne.

In practice it is entirely feasible to employ a heterodyne of any strength; and by using a high anode

Fig. 21.

potential (e.g., 100–200 volts) the grid can be maintained permanently negative in potential, so avoiding any inconvenience from grid damping despite the large fluctuation of grid potential. Suppose the mean grid potential OL (Fig. 21) is chosen to bring the point P to the foot of the characteristic; and the heterodyne is strong enough to sweep over the curve between N and Q, NP being nearly all horizontal and PQ being nearly all straight at the slope $di_a/dv_g \equiv g$. The rectification then becomes nearly " perfect," and the rectified current as found in Section 7 approaches $0{\cdot}45g$ LM$/\sqrt{2}$. The amplitude LM fluctuates at the acoustic rate between $(b+a)$ and $(b-a)$, so that the signal current tends towards the value $0{\cdot}45g \times \sqrt{2}a = 0{\cdot}90g\mathcal{E}$ as the heterodyne strength is increased, provided that the filament emission is adequate to prevent Q from reaching the convex upper bend of the curve.

In most " R " triodes g is about 300 micro-amperes per volt per volt; so that with a very strong heterodyne we have signal current

$$S = 0{\cdot}90 \times 300\mathcal{E} \text{ micro-amperes}$$
$$= 270\mathcal{E} \text{ micro-amperes}$$

This value is to be compared with the value $128\mathcal{E}$ found in the last section for a heterodyne amplitude of 2 volts. It is thus clearly worth while to use a heterodyne of adequate strength. Referring to Fig. 9, with heterodyne reception it is the slope and not the ordinate of the curve which should be made as large as possible; so that a heterodyne strength of some 15 volts would be suitable, and would give a sensitivity slightly exceeding the above $270\mathcal{E}$ micro-amperes.

13. Cumulative Grid Rectification with Heterodyne.

Owing both to uncertainty as to the equation of the i_g/v_g characteristic and to difficulties of the integration involved in the cumulative action, it is not possible to write down an expression for the instantaneous anode current, as has been done in the case of anode rectification. We have seen in Section 9 that the time-constant of the circuit can be reduced to about 75 micro-seconds, and as the acoustic variation of high-frequency mean anode current is relatively slow (with period, e.g. of 1 000 micro-seconds), it is probably sufficiently accurate to neglect the time effect of the condenser and take the high-frequency mean of grid potential at any instant as sensibly equal to the final value it would assume under continued application of the signal amplitude obtaining at that instant.

With this assumption, the high-frequency mean of anode current fluctuates between

$$\frac{d^2i_g}{dv_g^2} \cdot \frac{di_a}{dv_g} \cdot \frac{(b+a)^2}{4} \equiv K\frac{(b+a)^2}{4}, \text{ say,}$$
$$\frac{1}{R + \dfrac{di_g}{dv_g}}$$

and

$$K\frac{(b-a)^2}{4}$$

Hence signal current is $S = Kab = \sqrt{2}Kb\mathcal{E}$.

The value of K already found (Section 9) for a small potential difference on the grid is, for an " R " triode, 1 000; and if we take $b = 0{\cdot}14$ volt, which is the highest value for which the formula is applicable, we get

$$S = \sqrt{2} \times 1\,000 \times 0{\cdot}14\mathcal{E} \text{ micro-amperes}$$
$$= 200\mathcal{E} \text{ micro-amperes}$$

If, on the other hand, b lies between 1 volt and 5 volts, the mean anode current (from Fig. 19) fluctuates between $210(b+a)/\sqrt{2}$ and $210(b-a)/\sqrt{2}$. Hence

$$S = 210\sqrt{(2)}a \text{ micro-amperes}$$
$$= 420\mathcal{E} \text{ micro-amperes}$$

14. Comparison between Anode and Cumulative Grid Rectification with Heterodyne.

The signal currents produced by a sustained signal $\mathcal{E}$ have been found to be given, according to the strength of the heterodyne P.D., approximately by the several formulæ collected in Table 3.

TABLE 3.

Strength of heterodyne (volts, R.M.S.)	Signal current in micro-amperes, with		Ratio
	Anode rectification	Cum. grid. rectn.	
0·1	6$\mathcal{E}$	200$\mathcal{E}$	30
2	128$\mathcal{E}$	420$\mathcal{E}$	3
> 15	270$\mathcal{E}$	Very small	Very small

Hence it can be seen that with suitable values of the heterodyne strength, and without allowing for the damping introduced in the cumulative grid rectifier, this would be distinctly superior to the anode rectifier. But in circuits where the damping must be taken into account, there is probably little to choose as regards sensitiveness.

15. ANODE RECTIFICATION WITH DAMPED WAVES.

Let the incoming signal applied to the detector be now

$$e = a\epsilon^{-mt}\sin pt$$

As before, we take the anode characteristic to be

$$i_a = \alpha + \beta v_g + \gamma v_g^2$$

and we shall suppose that the damping exponent m is very small compared with p. Then the anode current at any instant is

$$\begin{aligned} i_a &= \alpha + \beta a\epsilon^{-mt}\sin pt + \gamma a^2\epsilon^{-2mt}\sin^2 pt \\ &= \alpha + \beta a\epsilon^{-mt}\sin pt + \tfrac{1}{2}\gamma a^2\epsilon^{-2mt}(1-\cos 2pt) \end{aligned}$$

Integrating this expression over the number N of complete periods per spark, we obtain

$$\begin{aligned} \int_0^{\frac{2\pi N}{p}} i_a dt &= \beta a\left[\frac{-\epsilon^{-mt}\cos pt}{p}\right]_0^{\frac{2\pi N}{p}} \\ &\quad + \frac{\gamma a^2}{2}\left[\frac{\epsilon^{-2mt}}{2m}\right]_0^{\frac{2\pi N}{p}} + \frac{\gamma a^2}{2}\left[\frac{-\epsilon^{-2mt}\sin 2pt}{2p}\right]_0^{\frac{2\pi N}{p}} \\ &= -\frac{\beta a}{p}\left(\epsilon^{-\frac{2\pi Nm}{p}} - 1\right) - \frac{\gamma a^2}{4m}\left(\epsilon^{-\frac{4\pi Nm}{p}} - 1\right) \\ &= \frac{\beta a}{2\pi n}\left(1-\epsilon^{-\frac{n\dot{\iota}}{x}}\right) - \frac{\gamma a^2}{4n\delta}\left(\epsilon^{-\frac{2n\dot{\iota}}{x}} - 1\right) \end{aligned}$$

where n is the frequency, δ the decrement, and x the number of sparks per second.

The first of these two terms is the net quantity of electricity which would be passed through a conductor of conductance β which is independent of the current (i.e. following Ohm's law); it is only not zero on account of the damping. The second term expresses the rectification due to the curvature of characteristic, and with practical signal strengths vastly exceeds the first, which may therefore be ignored. Hence

$$\begin{aligned} \text{mean } i_a &= \frac{\gamma a^2}{4}\left(1-\epsilon^{-\frac{2n\dot{\iota}}{x}}\right)\frac{x}{n\delta} \text{ approximately} \\ &= \frac{a^2}{4}\frac{d^2 i_a}{dv_g^2}\left(1-\epsilon^{-\frac{2n\dot{\iota}}{x}}\right)\frac{x}{2n\delta} \end{aligned}$$

Now suppose $n = 10^5$ periods per sec., $\delta = 0{\cdot}1$ and $x = 500$; then $n\delta/x = 20$, and

$$\begin{aligned} \text{mean } i_a &= \frac{a^2}{4}\frac{d^2 i_a}{dv_g^2}(1-\epsilon^{-40}) \times \frac{1}{40} \\ &= \frac{1}{40}\left(\frac{a^2}{4}\frac{d^2 i_a}{dv_g^2}\right) \text{ approximately} \end{aligned}$$

Hence the signal current is only one-fortieth of what it would have been had the wave been undamped and of maximum value equal to the first maximum of the damped train.

Substituting the value of $d^2 i_a/dv_g^2$ in the "R" triode, namely, 32 micro-amperes per volt per volt, we have signal current $S = a^2/5$ micro-amperes. If the wave had been undamped, however, and a suitable heterodyne had been used, it follows from Section 12 that $S = 270\mathcal{E} = 200a$. Hence the ratio of signal current when working with heterodyne to signal current when receiving a damped train of the frequency and decrement already stated is $(200a) \div a^2/5 = 1\,000/a$. If, for example, a has the value 0·1 volt, this ratio is 10 000.

Probably a fairer comparison is between undamped waves and spark trains having the same R.M.S. value, rather than the same initial amplitude. The R.M.S. value over one spark period of our damped train $e = a\epsilon^{-mt}\sin pt$ is

$$\begin{aligned} \mathcal{E} &= \tfrac{1}{2}a\sqrt{(x/n\delta)} \\ &= \tfrac{1}{2}a\sqrt{(1/20)} \text{ in our numerical instance} \\ &= 0{\cdot}11a \end{aligned}$$

The signal current with a heterodyned undamped signal of this strength is therefore

$$\begin{aligned} S &= 270\mathcal{E} \\ &= 270 \times 0{\cdot}11a = 30a \end{aligned}$$

The ratio $1\,000/a$ found for equal initial amplitudes thus becomes, for equal R.M.S. values,

$$30a/(a^2/5) = 150/a$$

With $a = 0{\cdot}1$ volt as before, this ratio becomes 1 500.

In the largeness of this figure, it is suggested, lies the chief explanation of the much superior ranges of continuous-wave transmitters as compared with spark transmitters of equal radiated power.

16. EFFECT OF IMPEDANCE IN ANODE CIRCUIT.

In all the foregoing analysis it has been assumed that the anode potential is unchanged by the advent of the signal. In any well-designed receiver this cannot be the case; for the impedance to the signal current offered by the telephone (or other indicating instrument) must be given an appropriate value, which is not negligible. The effect of this impedance, which has hitherto been tacitly ignored, is to reduce the values of the signal currents from the values calculated and observed in the foregoing sections. We proceed to find the correction which must be applied to the signal current S when there is no appreciable impe-

dance of the indicating instrument T (Fig. 22) in order to arrive at the actual signal current S' when there is an impedance X.

It is to be noticed, first, that it is not an impedance to high-frequency currents with which we are concerned, for this is in practice reduced sensibly to zero by the shunting condenser C; it is the impedance (X) of T and

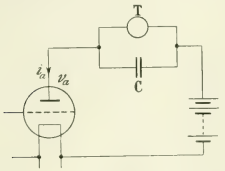


FIG. 22.

C in parallel to the acoustic fluctuations constituting the signal currents. In general terms, we have

$$S' = S - XS'\frac{di_a}{dv_a}$$

$$\therefore S' = \frac{S}{1 + X \cdot \frac{di_a}{dv_a}}$$

The correcting factor $1/(1 + X \cdot di_a/dv_a)$ is therefore to be applied to any of the foregoing calculated or observed signal currents in order to allow for the effect of the impedance X of the particular indicating instrument for the particular signal current, and with the particular anode-anode slope conductance di_a/dv_a of the triode in use.

The magnitude of X is, of course, under the control of the designer. It should usually be chosen to make S'^2X a maximum, in which case $X = 1/\frac{di_a}{dv_a}$; that is, the impedance should be equal in magnitude to the anode-anode slope resistance of the triode. With this optimum condition, we have

$$S'_{opt.} = \tfrac{1}{2}S$$

In the case of cumulative grid rectification, the appropriate value of di_a/dv_a is usually that obtaining over the straight region of the characteristics—about 30 micro-amperes per volt per volt in the "R" triode; but in the case of anode rectification, where we are necessarily working on the curved region, some lower value depending on the non-signal state point must be taken. This introduces no complication where weak signals are dealt with; but where a large range of grid potential is swept over, some average value of di_a/dv_a must be taken. Since the choice of the precise optimum impedance X is not a matter of much practical moment, it has been thought inadvisable to complicate the investigations in this respect.

DISCUSSION BEFORE THE WIRELESS SECTION, 1 MARCH, 1922.

Dr. W. H. Eccles: First of all I ought to thank the authors for venturing into a somewhat chaotic region and enforcing order therein. A great many papers have been written on this subject, but as far as I can remember there has been no paper covering the same ground in a systematic manner combining experiment and theory so elegantly. The procedure adopted is the ideal one of checking every calculation by a measurement. All the theory is based on the static characteristics, and in particular on those characteristics in which the anode potential is maintained constant. If we take that starting point, there is another way of tackling the theory of rectification which I think is rather simpler and more practical than the use of Taylor's theorem as adopted by the authors. Taylor's theorem expands the function in a series of which the coefficients are differential coefficients at the origin; but instead of using Taylor's theorem we may simply write down that the anode current is of the form:

$$i_a = \alpha + \beta e_g + \gamma e_g^2 + \delta e_g^3 + \ldots$$

where i_a is the anode current, e_g is the grid voltage, and the other symbols are functions of the anode voltage, being constants if this is constant.

By taking four or five points these constants can be determined numerically. The grid voltage is of the form

$$e_g = v + E_g \cos \omega t$$

where v is the steady adjusting voltage applied between grid and filament. The undisturbed anode current is obtained by putting $e_g = v$, and if this is subtracted from the general value we obtain

$$\beta E_g \cos \omega t + \gamma(2vE_g \cos \omega t + E_g^2 \cos^2 \omega t) + \delta(3v^2 E_g \cos \omega t + 3vE_g^2 \cos^2 \omega t + E_g^3 \cos^3 \omega t) + \ldots$$

On integrating over a second of time we get the quantity of rectified electricity flowing round the circuit. The result is

$$\tfrac{1}{2}\gamma E_g^2 + 3(\tfrac{1}{2}\delta v + \epsilon v^2)E_g^2 + \ldots$$

This expression agrees in form with the authors' results. Plotting the expression with values of v as abscissæ we can compare with the curves given by the authors. If we neglect third- and fourth-degree terms in E_g we obtain a horizontal straight line. If we then take in the third-degree terms we get another straight line, but sloping. If we then take in the fourth-degree terms, we get a parabola. The fact is that none of these fits perfectly the authors' results. Theirs is really a straight line in the middle—straighter than a parabola, but it is bent at the ends. The authors have taken the extreme case of anode voltage constant; the other extreme case, namely, anode current constant, has not been touched. The case of anode current will arise when a saturated diode is used in series with a triode adjusted for rectifying at either the low-current or high-current rectifying

point, an electrostatic voltmeter or other voltage-operated instrument being employed as indicating instrument. For discussing this case we assume

$$e_a = a + be_g + ce_g^2 + de_g^3 + \ldots$$

and determine the constants by fitting points on the constant-current characteristics. The analysis is precisely as before. Again, when the grid current is employed to rectify the input voltage, as in the cumulative method of rectification, a similar equation is assumed for the grid current, the constants determined by aid of the grid characteristic, and the analysis pursued as before. It is easily seen that the rectification is much more perfect in this new constant-current method than in the constant-voltage case treated by the authors. There are, however, all sorts of intermediate cases; in fact, in practice nearly all the cases we meet lie between those two extremes. It may be that they are nearer to the case the authors take than to the other, but that depends on the electrical constants of the apparatus included in this anode circuit. Anything included in the anode circuit must have a considerable effect in the case of high frequencies. The authors, of course, have been checking their theory by the use of low frequencies. If we pass from 90 periods per second to 900 000 periods per second, for example, there is a change of 10 000-fold in every impedance produced by condensers or inductances. There is thus some danger in arguing from low frequencies to high frequencies. For instance, the capacity current between grid and anode will be very much larger in one case than in the other, because the impedance is 10 000-fold less at high frequency than at low. Therefore we might say that by the use of low frequency the authors have limited themselves to an ideal set of circumstances. Theirs is, in fact, the ideal case assumed when it is desired to keep the theory as simple as possible; and although the authors have confirmed that ideal simple theory of the triode and its circuit by means of these low-frequency experiments, I do not think that they have proved that the theory holds to the same extent for high frequencies.

Professor C. L. Fortescue : There are many points brought out in this paper which are not in keeping with the general experience of wireless engineers. Referring to Fig. 6, an anode detecting valve is not usually equally sensitive over a range of from -1 to -7 volts on the grid. On page 714 the ratio $d^2i_g/dv_g^2 \div di_g/dv_g$ is shown to increase indefinitely as the negative valve of v_g is increased, whereas in actual use the sensitivity is not found to go up continuously as the grid becomes more negative. The figures of 10 000 and 1 500 as the relative strengths with heterodyned continuous-wave signals and damped spark signals are, again, scarcely in keeping with actual observation. These discrepancies appear to be due to the fact that, under the conditions of working adopted by the authors, all reaction effects are avoided, and the paper is of great value in bringing out the true facts with regard to the pure detecting action of the three electrode tubes. The part of the paper dealing with the grid detecting circuits is perhaps the most interesting. The graphical construction on page 712 provides a theoretical justification for the practical attitude of regarding the grid-leak resistance and the effective grid-filament resistance as being in parallel. In this connection, it follows that there is no object in increasing the resistance of the grid leak to a value greater than, say, 5 or 10 times the effective grid-filament resistance. The comparison of the relative merits of the cumulative grid detecting circuit and the anode detecting circuit is a controversial point, and it is noticeable that the authors have omitted all reference to heavy shock effects due to atmospheric interference. The result finally arrived at will probably find general acceptance as a fair comparison of the two systems. With regard to the treatment of the heterodyne reception on page 716, it is interesting to note that if the equation

$$i_a = \alpha + \beta v_g + \gamma v_g^2 + \delta v_g^3$$

is used, terms involving $\cos(2p - q)t$ and $\cos(p - 2q)t$ come in and give audible beat notes when the local heterodyne frequency is either about one-half or about double the frequency of the incoming signal. These so called "harmonics" are caused by the lack of symmetry of the rectifier characteristic and are not due to imperfect wave-form of either the heterodyne current or the signal current. Two omissions are noticeable in the paper, viz. no measurements have been made of anode rectifying at the top of the anode-current curve, and no mention is made of combined cumulative grid rectifying and anode rectifying at the top of the characteristic. This latter is known to be the most sensitive state of a detecting valve, and actual figures obtained by the authors' methods would be very instructive.

Mr. J. Hollingworth : There is one point I should like to mention in connection with cumulative grid rectification, and that is the question as to whether the working out in the paper really holds strictly when the time-constant of the grid circuit becomes commensurate with the frequency of the supply. Taking Fig. 10(*b*), it can be seen that at low frequencies the condenser will, roughly, receive its full charge. From some experiments I was doing a little while ago, it appeared as if, when working with very low applied E.M.F.—certainly lower than the authors have been working with here—the cumulative grid action ceased abruptly; below a certain value there appeared to be no effect, and suddenly the rectification came straight on. If we consider the first period; in the first quarter of it the condenser charges up. It depends on the time-constant as to whether it reaches full voltage or not. Then in the later quarters, when the applied voltage is in the opposite direction, we have really the condenser discharging both through the grid leak and back through the valve and being helped back through the valve by the reversed voltage. It seems that, under certain conditions, the condenser may have completely discharged and got back to its original state before the voltage rises and starts recharging. In that case it is questionable whether there is any cumulative effect at all, because after each period the grid will really start from the same position again. I tried to work it out by the point-to-point method from a curve, working from period to period,

but it becomes very cumbrous because, as the authors say, even if a simple mathematical expression be used for the grid curve, the equations are extremely long. But it did seem to show that, under certain conditions, the condenser actually discharged itself. On the other hand the failure to build up may be due to loss of power, because the loss due to the grid path is mentioned, but there are other losses in the valve. I had a case not long ago where the actual loss in the grid-filament path was only 10 per cent of the whole, the remainder being transferred to the anode circuit by inter-electrode capacity and dissipated there. In the particular case referred to above, I do not think that was so, because I was not working on a tuned circuit; I was inducing into the valve from an aperiodic circuit. It certainly seemed that with a low value of voltage the rectification effect stopped altogether. Whether that is possible according to the theory, or was a mere accident, I do not know, because I have not been able to go into it in sufficient detail; but it makes one almost wonder whether in cases like this, in the construction for the curve, there should not be some recognition of the fact that there is something in the nature of an exponential leakage going on through the grid leak for part of the time.

Mr. F. J. Chambers: I should like to describe a little experiment which shows how the anode potential actually varies in cases of this kind. Let us assume (see Fig. A) that we have a large inductance, such as a

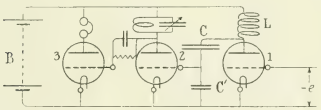


FIG. A.

telephone receiver, which may be several henrys, in the anode circuit of the valve 1; and let us take the case when the high-frequency oscillations are applied direct to the grid and filament of the valve. If a large condenser and a small condenser in series are connected between anode and filament in the case of this valve, and the common terminal of the two condensers is connected to the grid of a second valve, the potential at this point will, for practical demonstration purposes, vary sufficiently in accordance with the anode potential of the first valve. By inserting a flywheel circuit in the anode lead of the second valve, as shown, the frequency at which this potential is varied can be indicated conveniently. It will be found that the latter corresponds to the frequency of the applied oscillations, and that it is by no means a stray effect due to distributed capacity in the telephone receiver. Even though the anode inductance in the first valve may be very large, the high-frequency oscillations appear to be faithfully reproduced at the grid of the second valve—in fact, the larger the inductance, up to a point, the stronger and more faithful the reproduction, in my experience. Possibly the explanation may be this. When a sudden negative impulse is applied to the grid of the first valve, the anode current through L cannot instantly drop to the value determined by the valve characteristic, owing to the inertia of the circuit. The decrease of current is a more or less damped oscillation at the natural frequency of the circuit LCC'B, which may be, say, tens of thousands per second, or, if the condensers are large, an audible frequency. Under these conditions the anode current divides into two components, one through the valve, and the other a capacity-charging current which raises the anode potential. If the high-frequency negative impulses are of very short duration compared with the natural time-period of the circuit LCC'B, the lower-frequency trigometrical term and the exponential term may be neglected as regards the capacity current. The latter would then become a function of the applied E.M.F. at the grid of the valve, giving rise to corresponding variations of anode potential. I will leave the matter at this point to be dealt with by the mathematicians.

Mr. L. B. Turner: I wish to refer to the practical method of measuring the small changes in anode current superposed on the large anode current, which is, of course, a difficulty. The balance method shown in Fig. 3 works very nicely, and is extremely simple and convenient. I have noticed an abstract of a paper by H. Barkhausen in the January number of the *Radio Review*, wherein he recommends a circuit which is nearly identical with ours; but for some reason which, to me at any rate, is not apparent, he puts the galvanometer on the anode side of the high-tension battery instead of on the filament side, as we do. Consequently he has to produce his balancing E.M.F. by an extra battery, which is a practical objection. If the galvanometer is put on the filament side, we have 4 or 6 volts available from the filament battery; and that is generally quite sufficient, because the galvanometer has seldom a resistance of more than 1 000 ohms or so. With regard to the joint authorship of the present paper, I should like to say that any credit for the work is almost entirely due to Mr. Moullin. My share has lain chiefly in discussing the results at various stages and the lines of further investigation.

Professor G. W. O. Howe: The opening remarks in the paper as to asymmetric conductors and rectification raise a point of some interest as to the use of the word "rectification." It is questionable whether in these devices as used we are getting real physical rectification. If we read the original patent specification taken out by Fleming for the two-electrode valve, we find its action described as depending on the fact that there are present two electrodes in a different state, namely, an incandescent electrode and a cold electrode, and Professor Fleming points out very plainly that, in such a device, current can pass in one direction and not in the other direction. That is a physical rectifier. But, as ultimately used, even the two-electrode valve of Professor Fleming usually had in the anode circuit a battery, and its action in making the signals audible did not depend at all on the fact that the two electrodes were of different temperatures and that current could not pass in the other direction, because the superimposed high-frequency E.M.F. was

rarely of such an amplitude as to overcome the polarizing E.M.F., and hence the resultant E.M.F. acting on the valve was always in the same direction. This can be illustrated in an interesting manner by means of valves in which, instead of a cold and a hot electrode, there are two incandescent filaments, both kept at equal temperatures by means of batteries; such a valve operates like an ordinary diode—when both are employed with a polarizing battery. Such a valve in itself is not an asymmetric conductor; it is perfectly symmetrical, as can be seen by reversing the current. It is very convenient, of course, not to have to heat the second electrode, but if anyone wished they could use a diode in this way, with two heated filaments as electrodes. In the ordinary Fleming valve we have an arrangement by which current can pass in one direction but not at all in another, so that if we apply an alternating E.M.F. we have current in one direction and not in the other. With the two heated filaments on the other hand, we have a perfectly symmetrical conductor, working equally well in either direction; if, however, we put on a suitable polarizing E.M.F. and maintain a steady current, then by superimposing an alternating on the polarizing E.M.F. we get what is commonly called rectification, but it is a mathematical rather than a physical rectification. It does not depend at all on the fact that the arrangement is asymmetrical and passes current more readily in one direction than the other; it simply depends on the bend in its characteristic curve. In one respect I feel that the paper merits adverse criticism, in that it shows an absolute disregard of any previous work on the subject. So far as I have noticed, the authors have made no reference to the work of Van der Bijl. Those who are familiar with Van der Bijl's work and his book on thermionic tubes, will know that he discusses very fully the parabolic nature of the characteristic curve, and develops his mathematical treatment on that assumption. I think it would add to the value of the paper if reference were made to this and other previous work, and if some indication could be given as to what was old and what was new. The paper contains much valuable new work and is a very thorough investigation into the relative merits of the various methods of rectification.

Dr. N. W. McLachlan (*communicated*): I think that the first sentence in Section 12 of the paper requires some qualification. Granted that triodes did not saturate, the strength of the "local oscillator" could be unlimited. I use the term "local oscillator," which may be abbreviated L.O., to discriminate between heterodyne effects thus produced and those which arise due to incoming radiation from an external source. Broadly speaking, there are two methods of utilizing an L.O. which may be cited: (1) To induce into some part of the receiving circuit before amplification; (2) to inject or induce into some part of the amplifier before rectification. In case (1) the L.O. can be introduced into the tuned circuit immediately before the high-frequency amplifier. With selective receiving circuits there is less chance of radiation from the aerial, and the strength of the L.O. is smaller than that where the introduction occurs earlier in the system. If the signals are weak, several high-frequency amplifying triodes will be employed, and the current induced by the L.O. can therefore be comparatively small, since it undergoes amplification. The maximum induced current from the L.O. is governed by the saturation current of the last amplifying triode. From this standpoint there is no advantage in having a rectifier whose saturation current exceeds one-half that of the last amplifying triode. It may happen that the current from the L.O. is so large that saturation does occur, leading ultimately to distortion and reduced signals. The lower the decrement of that part of the receiving circuit where the L.O. is applied and the higher the frequency of the beat note, for a given ratio of induced current to signal current, the greater must be the current in the oscillator itself. The coupling between the receiving circuit and the L.O. should be loose so that the signal E.M.F. induced in the L.O. coupling coil is small compared with that in the generating circuit of the oscillator. This applies more particularly when a heavy atmospheric arrives. Thus the L.O. itself should be comparatively strong to ensure stiffness. Moreover, in order to avoid spurious coupling between the L.O. and the remainder of the receiving circuit, the L.O. must be effectively screened and an auxiliary coil used for coupling. There is a further limitation in respect to saturation, apart from that already mentioned. Suppose the induced L.O. current with a normal signal, this latter being assumed small in comparison, is just sufficient to operate the last amplifying triode on the verge of saturation. When a strong atmospheric arrives, one or more triodes are saturated, with consequent distortion, and the signal is mutilated and rendered unreadable. If this happens in the high-frequency amplifiers, the audio-frequency circuits and amplifiers which follow are worked under false conditions. Moreover, any mollifying influence which these latter might have on the atmospheric is prevented. Hence it is necessary, in order to utilize the complete circuit in the optimum manner, that none of the amplifying triodes, nor the first rectifying triode, should reach saturation. At this point it is of interest to mention a well-known pseudo-atmospheric-reducing artifice in which the rectifying triode is used as a "limiter." The efficacy of this scheme probably lies mainly in a physiological rather than in an electrical realm, and the greater signal readability is due to the less-violent aural bombardment. To illustrate case (2), we may cite the special instance in which the L.O. is injected between the grid and filament of the rectifying triode. Since there is no previous amplification, the L.O. will not saturate the amplifying triodes and will itself in general require to be stronger than in case (1). Screening ought to be adopted, or the L.O. will find an alternative entrance to the receiving circuit, and this is what it is desired to prevent. Apart from the point raised hitherto, in regard to saturation arising from atmospherics, it is evident that the maximum applied strength of the L.O. is controlled by the saturation of the rectifying triode. The "perfect" rectification to which the authors refer in Section 7 can be most readily realized in a recording triode having a relay in its anode circuit. The question of saturation from atmospherics does

not then arise. For, assuming that the triode is not worked at saturation, an increase in anode current, due to the atmospheric during a dot or a dash, does not affect the relay, since the latter is already on the marking stop. With a circuit of this nature, the condition specified by the authors in Section 16 will obtain, since the impedance of the relay, and therefore the potential difference across it, will be appreciable. In order to obtain a sufficiently rapid rise of current through the relay at, say, 150 words per minute, it may be essential to augment the anode battery voltage or to connect several rectifying triodes in parallel, thereby apportioning a greater share of the existing voltage to the relay during conductive periods. There are occasions when it is beneficial to effect rectification at the upper bend of the anode-current/grid-voltage characteristic. Although the authors have not treated this specifically, I think their analysis will be sufficiently accurate for most practical purposes in this instance also. Coming now to cumulative grid rectification, this is extremely useful for reception, provided the atmospherics are of minor importance. In a system subject to strong atmospherics, the use of such a device would be fatal, since the time for the condenser to discharge from an abnormal voltage to a sufficiently small value would exceed the duration between Morse characters. This depends, of course, on the speed of transmission. Consequently the spacing would be swamped and the Morse become unintelligible. This effect could not be adequately counteracted by reducing the resistance of the grid leak, at least not without appreciable sacrifice in the working efficiency.

Messrs. E. B. Moullin and **L. B. Turner** *(in reply)*: Dr. Eccles has set out an alternative method of analysis of rectification due to curvature of characteristic. Fundamentally it is, of course, the same theory; but he proposes to find the coefficients of the significant terms of the power series arithmetically, whereas we have found them graphically. His modification offers, no doubt, an advantage on the score of ease of numerical computation from any particular static characteristic; and, as he has shown, it is useful for studying analytically how the rectification for a given signal depends upon the state point on the curve. In a general theory of rectification, however, the expansion with differential coefficients has much to recommend it; for rectification depends upon the curvature of the characteristic, and Dr. Eccles's numerical coefficients have to be translated into differential coefficients—for example, $f'''(v_0) = 6\delta$—before their geometrical and physical significance is fully appreciated. It is an interesting point that the process of averaging over a complete period divides the successive terms of the differential coefficient series representing the rectified current by numerical coefficients which rapidly increase; consequently the terms involving $f''''(v_0)$, etc.—or Dr. Eccles's coefficients ϵ, etc.—are relatively unimportant even though the coefficients ϵ, etc., are not necessarily themselves small. The method of analysis used in the paper is, we think, the easiest way of showing up this point. Another way of appraising the relative practical advantages of the two methods of analysis is this. Although it may be possible to draw a parabola with axis vertical through three points so that the difference between the parabola and the true curve is everywhere very small, the parabola will not in general osculate the curve at every point. But, for Dr. Eccles's coefficient to give the true second differential coefficient of the curve, the parabola must have at least second-order contact at every point. We have found experimentally that this is a very practical consideration. For instance, with reference to the curve of Fig. 1, if a parabola is taken with vertical axis and vertex on the voltage axis of co-ordinates, cutting the curve at $-3{\cdot}6$ and -7 volts, its ordinates differ nowhere from the true curve by more than 1 per cent; its second differential coefficient is, however, 15 per cent less than that found graphically for the true curve, and experiment showed that the value derived graphically gave the true rectified current. Dr. Eccles refers to the use of a triode rectifier with constant anode current. This is of course possible, but requires that there shall be a saturated diode as the anode circuit impedance, an inconvenient arrangement on account of the extra batteries and certainly not common practice; further, it requires an output instrument or indicator taking no current, which would, no doubt, be the grid-filament of another triode. The usual output instrument of the rectifier is a transformer followed by an acoustic amplifier, or a telephone. These are current-operated instruments, and should be designed to have an optimum, not infinite, impedance; and this finite impedance produces a departure from constancy of anode potential which is dealt with in Section 16 of the paper. Dr. Eccles suggests that low-frequency tests may not satisfactorily expose the behaviour of the rectifier at wireless frequencies. But when he states that "anything [reactance] included in the anode circuit must have a considerable effect in the case of high frequencies," and that "for instance the capacity current between grid and anode will be very much larger in one case than in the other," is he not forgetting that there should be only a negligibly small high-frequency fluctuation of anode potential in a rectifier triode? The anode impedances are appropriate to acoustic frequencies, and contain by-pass condensers designed to give zero reactance for the wireless frequency. For this reason the grid-anode capacity, often so important and troublesome in high-frequency amplifiers, is not of much significance in the rectifier triode as ordinarily used. Further, and more generally, whereas Dr. Eccles says that although our experiments have confirmed the ideal simple theory of the triode and its circuits for low frequencies he does not think that the theory is so applicable for high frequencies, we should prefer to put it that the theory is sound for every frequency, but that if stray capacities are present they must be taken into account if and when they become important.

The consideration of atmospherics was not regarded as being within the scope of the paper; but it is quite true, as Prof. Fortescue says, that such consideration may introduce strong objections to the use of cumulative grid rectification. Dr. McLachlan raises the same point and even goes so far as to say that "the use of such a device would be fatal." We would remark that,

although no station is untroubled by atmospherics, the device is, in point of fact, of the commonest.

Anode rectification at the top bend of the curve, also mentioned by Prof. Fortescue, does not seem of great practical interest, because it can only be practised with inconveniently high anode potential or very dull filament, or else with positive grid potential. It is not our experience that it is advantageous to combine cumulative grid with top-curve anode rectification, but we have made no definite investigation of the point.

Although Prof. Howe favours the restriction of the term "rectification" to non-return action, he does not suggest any alternative term for the action of wireless detectors—the rectification clearly defined in our introductory paragraph. Any discrepancy, too, between our view and Prof. Howe's in the matter of asymmetric conduction is only one of definition of terms. The behaviour we refer to is the asymmetry about the no-signal state point, an asymmetry which remains even in the diode with both electrodes heated in the presence of the suitable polarizing E.M.F. To Prof. Howe's criticism that the paper shows a disregard of previous work we must, to some extent, plead guilty. But if we have here presented calculations already published elsewhere, they were at least new to us, being instigated by a sense of ignorance which might, possibly, have been removed by a more thorough perusal of recent literature. We believe that the experimental method of this paper is new, and if any of the results should prove to be merely confirmative of those of other workers, they may still be of value as obtained by a different method. On referring to Van der Bijl's book on "The thermionic vacuum tube," we find that he makes no quantitative analysis of cumulative grid rectification, nor does he investigate the effect of strength of hetrodyne oscillation; and although he deals only with a parabolic characteristic, he does not show, as we have done, over what range this is justifiable.

ELECTRO-FARMING, OR THE APPLICATIONS OF ELECTRICITY TO AGRICULTURE.

By R. Borlase Matthews, Member.

(*Paper first received* 15*th September*, 1921, *and in final form* 1*st March*, 1922; *read at* The Institution 30*th March*, *and before the* Irish Centre 8*th May*, 1922.)

Summary.

The term "electro-farming" is defined, and the importance of agriculture as the world's largest industry is emphasized. Based on experimental work conducted on a commercial scale, the author considers that the highest efficiency in farming can be reached only by electrical methods. The applications of electricity on the farm are many and are shown in an exhaustive table under the following classification :—(1) Uses in the farm buildings, (2) on the farm land, (3) crop treatment, (4) in the farm house. The farmer is really a manufacturer, but his present methods are based on abundant cheap labour and unlimited time. Before the engineer can apply modern manufacturing principles he must understand the technicalities of farming.

Data are given to show that the farm load is an attractive one from the central station standpoint, and a simple distribution system is outlined. Restricted maximum demand is advocated as a basis for power rates, as it encourages the extended use of electricity.

Simple and robust design is essential in all farm machinery. The use of electric motors is discussed and tables are given of motor sizes required for various duties and of the work done per unit consumed. Inexpensive and simple arrangements of portable motors are described.

In the Appendix, which follows the classification stated above, examples are given of the profitable use of electric light, e.g. in avoiding milk loss, increasing winter egg production, etc. A suitable wiring system is described. Other farm-building uses of electricity considered in some detail are milk sterilization, and the incubation and rearing of poultry. Reference is made to the weather reports issued by wireless from the Meteorological Office. Irrigation is considered, and the present position of electric ploughing is discussed at length. Single-rope haulage is the most suitable method at present available and is adapted for use in small fields. In the case of harvesting machinery the author's arrangement of an independent electric drive for the knives and binding mechanism is advocated, because it enables the machine to do more work per day. Electroculture is stated to give a certain minimum increase in crop, and suitable apparatus is suggested.

The artificial drying of hay and cereals under adverse weather conditions is shown to be practicable, while a successful Continental electrical method of ensilage is described and illustrated. A brief note on the importance of accurate account-keeping (on the author's "Auto-Countancy" system) and a description of a simple electrical book-keeping machine are given at the end of the Appendix.

The conclusions are arrived at that any farm machine which revolves or has revolving parts can be operated by an electric motor more effectively and economically than by any other means, and that electric treatment produces results that cannot be obtained otherwise than by electric means.

Definition.

Any and all applications of electricity to agriculture may be very concisely defined as electro-farming. This use of the term "electro-farming" must be interpreted in its broadest sense, i.e. whether the electrical medium provides merely mechanical methods (as in the case of the group driving or individual motor driving of existing machinery) or whether the methods are exclusively electrical (as instanced in high-tension discharges above growing crops).

Importance of Agriculture.

Agriculture is the largest industry in this country (and in the world for that matter). In England and Wales alone there are 418 000 farms and small-holdings, of which 36 000, or nearly 10 per cent of the total, have each an area of over 150 acres. There are 13 500 farms (or about $3\frac{1}{4}$ per cent of the total number) of over 300 acres each. Hence, if use were made of electricity to any considerable extent in farming operations, there would be an enormous demand both for apparatus and for current.

Full-Scale Trials.

For some time past the author has been making careful experimental investigation into the practical possibilities of the use of electricity in agriculture, and in this paper it is proposed to give the outcome of the results of his practical experience.

The problem has been tackled from a commercial rather than from a laboratory standpoint. That is to say, the experimental work has been carried out on the lines of actual working farming, as it would have to be done by those who farm for a living, with strict regard, therefore, to profit and loss. This method is undoubtedly slow from the point of view of obtaining results quickly, but on the other hand commercially it is the only satisfactory way. Nearly all the author's experiments have been carried out on his own farm of 600 acres at Greater Felcourt, East Grinstead. At the same time he has been making a careful study of Continental methods of attacking the same problem, and has thereby gained valuable experience of a most practical nature.

As in all other industries, the successful solution of the application of electricity is not merely a matter of belting a standard motor to existing machinery. The conditions and circumstances of farming are peculiar to that industry, and not the least of these problems is the fact of the limited seasonal use of much of the

machinery, coupled with the fact that a large proportion of the labour available is prejudiced against, and unused to, machinery in any form. Again, as is well known, there are many varieties of farming, e.g. mixed, dairy, breeding, etc., and these cause a considerable variation in the requirements.

The conclusion arrived at by the author is that in the future, for the most successful operation of farms, the use of electricity will be essential from the points of view both of cutting down the total cost of power and labour and of obtaining an increased output. That is to say, if the efficiency of farming is to be improved, a change from present methods is imperative, and the author maintains that an increased efficiency, including the circumvention of adverse weather conditions, is easily obtained by electrical methods. Incidentally, the application of electricity to agriculture will do much eventually to raise the status of the labourer.

Electricity on the Farm.

The question as to what extent it is advantageous to apply electricity on any farm depends naturally on the size of that farm. For farms of under 150 acres careful thought must be given to ensure that an adequate return is obtained for the capital expended, as the number of hours of use of each machine is limited. Similar care must of course be taken in designing installations for larger farms but, as the hours of use are longer, it is not so easy to make a mistake in regard to the equipment. On every farm the uses of electricity may be roughly classified under the following headings :—

(1) Uses in the farm buildings.
(2) Uses on the farm land.
(3) Uses in connection with the treatment of gathered crops.
(4) Uses in the farm house.

Table 1 has been compiled by the author to give an indication as to the very wide scope which exists for electricity on a modern farm. All the particulars are collated from actual practice on present-day farms, but naturally all the methods are not to be found on, and further are not suitable for, any one farm. Incidentally this table will be found of considerable assistance when considering the possibilities of the applications of electricity on any particular farm. It will be noted that the table is divided into the main classifications given above.

Table 1.

Some of the Uses of Electricity on Farms.

(1) In the Farm Buildings.

(*a*) *Electric light.*

Electric lighting in dairy, cow barns or byres ; * general electric lighting of the buildings and yards.*
Electric lighting for intensive feeding of sheep, pigs, poultry * and other stock during the winter.

* These machines are in operation on the author's 600-acre farm.

Table 1—*continued.*

(*b*) *Food preparation for live stock.*

Electric driving of the following :—
- Chaff cutters.*
- Chaff dust-extractors.
- Root pulpers, slicers and cutters.*
- Cattle-cake breakers.*
- Corn crushers, kibblers, rollers, grinders and grist mills.*
- Disintegrators for ditto.
- Corn or maize shellers, huskers and shredders.
- Food sifting and mixing machines.
- Meat grinders and mincers.

(*c*) *Dairy.*

Electric driving of the following :—
- Milk or cream separators.*
- Cream ripeners.
- Butter churns.*
- Butter workers.*
- Butter cutting and printing machines.
- Butter tampers.
- Refrigerators.†
- Ice breakers.
- Ice-cream making machines.
- Cheese curd breakers and curd grinders.
- Casein grinders.
- Milk-churn transporters.
- Milk-churn elevators.
- Milk-bottle cleaners and fillers.*
- Milk shakers.
- Milk and cream pasteurizers.
- Milk clarifiers or centrifuges.
- Centrifugal fat-testers.
- Milk cooling and circulating pumps.
- Milk-bottle capping machines.*

Electric sterilization of milk by :—
- (*a*) Electrolytic bath and
- (*b*) Mercury-vapour lamps.

Electric heating of incubators for testing bacterial content of milk, etc.

(*d*) *Poultry.*

Electric light in laying houses (to increase egg production).*
Electric egg tester.*
Electrically heated incubators, hovers and foster mothers.*
High-tension electrical treatment.
Electric fans for circulating air in incubators.
Electric driving of the following :—
- Bone grinders.
- Grain crushers, grinders, kibblers and grist mills.*
- Seed cleaners and sorters.
- Mixing machines.

(*e*) *General applications of electric power.*

Pumping of water for domestic use and for stock (open tank and pressure systems).*
Pumping of liquid manure.*
Pumping of sewage.

* These machines are in operation on the author's 600-acre farm.
† These machines are about to be installed on the author's farm.

TABLE 1—*continued.*

White-washing machines.
Portable winch.
Hay hoists.
Hay elevators and transporters.*
Food transporter.
Cart loader.
Horse clippers and groomers.*
Sheep shearers.*
Milking machines.*
Grindstone (also mower-knife grinder).*
Workshop for repairs to farm machinery.* (Including grindstone, emery wheel, drilling machine, portable electric drilling machine, lathe, forge blower, electric soldering-iron, electric glue-pot, etc.)
Electric thermo-couple long-distance thermometer for tuberculosis test of cows and pigs.
Electric branders for marking cattle.
Electric fans for driving off flies in the cow houses.

(*f*) *Farm Office.*

"Auto-Countancy" electric book-keeping machine.†
Electric telephones,* clocks,† bells and hooters.*
Wireless telegraphy and telephony for weather reports.†

(2) ON THE FARM LAND.

Irrigation by means of electrically operated pumps,

(*a*) General,
(*b*) Shallow root crop, and
(*c*) Deep root crop.

Liquid-manure distribution by means of electric pumps.
Artificial-manure distribution by electrically operated machines.
Ploughing by electric tractor or electric haulage set.†
Cultivation and harrowing by electric tractor or electric haulage set.
Hay mowing with electrically operated mower.
Hay making with electrically operated machines.
Hay drying in wagon by electrically operated blower.*
Corn-sheaf drying with electrically operated blower.
Hay elevators, electrically operated.*
Corn cutting and binding with electrically operated harvesting machine.*
Electrically operated potato digger.
Electrically operated fence-post driver.
Electrically operated stump and root pullers.

Treatment of growing crops.

Electro-culture by high-tension,† high-frequency electrical discharge, ozone treatment, mercury-vapour lamp treatment,

(*a*) for better growth,
(*b*) to destroy insect pests, and
(*c*) to strengthen the plants and so enable them better to resist the vagaries of the weather.

Electrically operated wet and dry sprayers for hop vines, fruit trees, etc.

* These machines are in operation on the author's 600-acre farm.
† These machines are about to be installed on the author's farm.

TABLE 1—*continued.*

Vehicles.

Electric tractors.
Electric milk vans * and lorries for general transport.

(3) CROP TREATMENT.

Preparation of seed.

Electrolytic seed bath (to produce heavier crops).
Treatment of seeds with ozone.
Treatment of seeds with mercury-vapour lamps.
Electrical germination of seeds.
Electrical seed dressing.
Electrical heat-treatment of seeds.

Gathered crops.

Electrolytic conservation of green food-stuffs.
Hay drying in stack by electrically driven fan.*
Grain drying by electrically driven fan.
Desiccation of vegetables and fruits by electric fan.
Electric pulping of fruits for supply to jam makers.
Electric driving of silage cutters.†
Electric driving of mechanical conveyer and pneumatic elevators for silos.†
Electric driving of the following :—
Automatic silage stackers.
Thrashing machine feeders, and straw trussers.*
Thrashing machines.*
Grain graders.
Winnower or fanner mills for cleaning seeds.*
Straw balers.*
Hay balers.
Straw and hay chaffers.*
Potato sorters.
Hop dryers, shredders and dryers (centrifugal).
Lucerne or alfalfa mills.
Flailing machines.
Malting machinery.
Clover, pea and bean hullers.
Seed cleaning and dressing.
Grain and chaff elevators.
Sack elevators.
Killing of mould growths.

Rural industries.

Electric operation of machines for :—
Peat and timber drying, seasoning, sawing * and working.
Cider milling and pressing.
Wool spinning and pressing, weaving and knitting.
Clog making.
Toy making.
Hop drying.
Drying of spent hops for litter.
Drying of spent cider apple refuse for cattle food.
Drying of spent sugar-beet refuse, potatoes, etc.
Concrete mixing.
Stone crushing.
Preparation of nitrogenous manures by electrical discharge.
Brewing of beer.
Manufacture of alcohol.

* These machines are in operation on the author's 600-acre farm.
† These machines are about to be installed on the author's farm.

(4) In the Farm House.

Electric lighting, electric heating, electric cooking and domestic electric power.*

General Observations on Table 1.

As will be gathered from this table, many of the applications of electricity to farming are closely allied to procedure in other industries, as they are after all dependent only upon broad general principles. In general, most of the problems associated with electrical drives inside the farm buildings are now solved—except that, as in other industries, many radical changes will have to take place in the design of the actual machines. Incidentally, as so many farm buildings are ill-adapted for the mounting of counter-shafts and the like, there will obviously be an increased demand for self-contained machinery. Further, owing to the lack of skill on the part of the farm labourer, the biggest demand will always be for that type of machinery which is practically self-contained and fool-proof. However, for the next few years, while farmers are conservatively "trying out" electricity, the portable motor will serve most requirements.

On the land, much slower progress has been made in applying electrical methods, due no doubt to the great initiative required on the part of the farmer and through lack of knowledge of the best methods of transmitting electricity over the farm.

If British farms are to compete successfully with the world's markets, certain changes will have to be made in their methods of agriculture. There are already signs of these changes, in the gradual adoption of more intensive cultivation, the institution of soiling crops, inter-cropping, and greater employment of artificial manures. Incidentally, these changes will favour the use of electricity on arable land, since the work will be more regular, and idle fallows will be eliminated.

Only a few days' work each year is required in any one field, and even this short time is occupied with such diverse operations as ploughing, cultivating, harrowing, rolling, hoeing, reaping and gathering. Electrical methods of performing these operations have now passed the experimental stage and are about to be introduced commercially on the sound basis that it will pay the farmer to adopt them.

Although, even under the best conditions, the load factor of an individual arable field is low, the completely electrically equipped farm has a load factor which is quite satisfactory from the central station point of view, especially when any farm is considered in conjunction with neighbouring farms.

A great deal of work that ought to be substituted by electric power is being done by manual labour on farms to-day. However, even progressive farmers are not usually aware that electricity can assist them, until an electrical engineer studies the situation and shows them the possibilities. A difficulty arises here, in that but few engineers have sufficient knowledge of the intimate details of farming methods to develop electrical methods without considerable study, and sometimes a good deal of investigation, before success is attained.

The general problem might be simplified if the farmer were looked at in another light. He is really a manufacturer who, commencing with certain raw materials, puts them into a more refined condition—with possibly a second process if he converts his refined materials into the form of animal flesh. In the course of this procedure all by-products are—or should be—fully utilized. Viewed in this way, it does not take an engineer long to realize that the lines upon which farms are normally worked are based upon an abundance of cheap labour and a disregard for time. On the other hand, the engineer will soon find that there are really serious difficulties in modernizing a business in which the load factor of each machine, or possible machine, is so low.

Current Consumption.

Continental experience shows that the annual consumption of electricity in farm buildings alone is proportional to the size of the whole farm and averages 10 kWh per acre. The consumption in the farm house would average 7 kWh per 33-watt lamp per annum, or an average of 210 kWh. To this must be added 800 kWh, for heating, cooking and domestic power. If the farm were very modern there would be in addition a consumption of 33 kWh per acre of arable land for ploughing, plus one-third of this for cultivation, electro-culture, electric silage, harvesting, etc., or a total of 44 kWh per acre.

Area of farm	Usual farm buildings, max. demand	Farm buildings, kWh per annum	Farm land, kWh per annum
acres	h.p.	kWh	kWh
1	—	10	44
150	3	1 500	6 600
300	5	3 000	13 200
600	15	6 000	26 400

These figures are already attractive to a central station, and as definite knowledge spreads as to the possibilities of the uses of electricity on farms the consumption should materially increase to the profit of both the farmer and the supplier of current.

The Supply of Electricity to Farms.

This is a subject so engrossing that it would occupy much space. However, at this juncture it is only proposed to touch upon some interesting features of present practice.

As the outcome of experience, practice in electric power distribution for agricultural purposes is settling down to a simple standard. While the main distribution may be at any pressure over 50 000 volts, in Europe a sub-distribution of 10 000 volts, three-phase, 50 periods, is becoming standard. In America, this sub-distribution is at either 13 200 or 6 600 volts, three-phase, 60 periods. The Continental standard final

* For details see the author's central station engineer's handbook, "Electricity for Everybody" (Electrical Press).

pressure for farm supply is 380 volts for three-phase motors, and for lighting, 220 volts single-phase (obtained between any phase and a neutral conductor). The electric distribution lines in such a case consist of 4 wires, the fourth or neutral wire also acting as a guard. At road crossings tall iron-lattice standards are employed, of such a height that if a wire gives way at either support it will not come into contact with ordinary traffic. In addition, each wire as it leaves a standard to cross the road is strengthened by one or two stays attached to insulators. This would seem to be a much simpler and more effective method than the use of cradles.

For economic and other practical reasons the number and size of transformers are reduced to a minimum. It is found that for farm work a useful minimum size is a 50-kVA transformer. From this transformer, supply distribution lines can be conveniently run in any direction for a distance not exceeding 2 500 yards (say 2 km). Every farm within reach of this local distribution is connected, and a good load factor is obtained. In Denmark, overhead lines of 25 mm^2 (0·039 sq. in.) are usually employed for farm supply; where the load is 50 kVA or more, a section of 35 mm^2 (0·054 sq. in.) is employed. To allow for the pressure-drop, the motors which are installed at the ends of the lines are wound for a voltage 10 to 15 per cent lower than normal. Of course, when several motors are running the voltage-drop has a marked effect upon the brilliancy of the lights. However, it is rarely that the bigger motors are operated in the evening, when the lights are mainly in use in the farm houses. This scheme is therefore both practical and economical.

The transformers and switches for Continental farm installations are now housed in artistically designed towers, instead of being mounted on poles, as is the practice in America. The height of these towers corresponds to that of the overhead lines. Combined strainer fuses are largely employed on the low-tension distribution systems. These are very useful, as, if one of them blows, the circuit can be re-established by a temporary bridging fuse, which is placed in position by an unskilled local man with the aid of a long pole. The central station staff can then effect the proper replacement at their leisure.

Unquestionably the best and cheapest method by which the farmer can obtain power is from a public distribution network, but where this does not exist he must install a properly designed independent plant—for electricity is now indispensable on the farm.

The author has devised an arrangement whereby the farmer's oil tractor can be made to give effective service until a permanent plant is available. The scheme comprises a special reinforced concrete runway, having strong side guiding kerbs. These kerbs always align the tractor in the same position facing the dynamo, which is mounted on a suitable pedestal and driven by an endless belt from the tractor pulley. The dynamo is attached by cam-clamping bolts to belt-tightener rails. The latter are provided with an adjusting screw operated by a crank handle. Thus the belt can be very quickly adjusted as the tractor is taken away or brought in.

Power rates.—It is to be hoped that central power supply undertakings will not stipulate for rates based on the horse-power of the motors connected. Such rates discourage a farmer from installing a number of motors—in fact, in America, in certain districts where such rates exist, farmers are installing oil engines to reduce the number of their electric motors. After all it is the maximum demand that affects a public supply, and maximum-demand meters, with a suitable time-lag, are reasonably cheap. With the aid of suitable technical advice it can be demonstrated to farmers that they can obtain better terms on a self-restricted maximum demand. Agricultural-implement manufacturers are already catering for this requirement by providing such machines as thrashers, in such a form that the work is carried out in two separate stages. In one machine the corn is thrashed and cleaned sufficiently for the farmer's own needs. In the second machine that portion of the corn from the thrasher that is intended for the market is finally dressed, cleaned and sorted. Either of these machines can be driven by a 5-h.p. electric motor, as compared with the $12\frac{1}{2}$-h.p. motor required for a standard full-size thrasher. Incidentally, fewer men are required to operate the small machine, although of course the whole process lasts longer. This, however, is not usually a disadvantage, in that the saving in wages for extra men more than compensates for the extra time taken. In this manner, and by the aid of self-restricted circuits, an average farm will offer a very satisfactory load factor for the central station.

Features of design.—Electrically operated farm machinery—both the mechanical and electrical portions—should be of such design and construction as rarely to need overhaul, for the farmer who makes a hobby of keeping machinery in repair is apt to neglect his crops and stock. This, in fact, is one reason why machinery is not employed to a greater extent on some farms. A trouble that is often encountered with farm electric motors is damage by moisture, due either to rain or to condensation. It is difficult to avoid this, unless to design the motors so as to be as waterproof as is feasible. Ball-bearing electric motors are to be preferred for farm use, if provided with good felt packings, as frequent lubrication is eliminated. Undoubtedly, the most practical motor for farm use is the three-phase squirrel-cage type. For farms of over 300 acres the author favours three-phase power installations on this account, coupled with the fact that, as soon as a public power supply is available, it is nearly certain to be three-phase supply, and so the farmer who already has a private installation will not have to change his motors.

Electric motors.—On a farm where other than manual power is employed in the barns, the machines most commonly in use are hay chaffers, root cutters and pulpers, grinding mills, cattle-cake breakers and firewood saw benches. These machines are chiefly used during the winter time, and even then for only a few hours daily. Hence, at first thought, the load factor of a farm does not appear to be very attractive. However, if electricity is available, experience shows that it will soon be employed for a variety of other purposes, if

only the attention of the farmer is drawn to its possibilities. A very important use, where water is not already laid on, is for driving the water pump for general farm purposes and also for domestic use. Still another service which may be reckoned among the essentials is the driving of a liquid-manure pump. If a dairy herd of more than 10 cows is kept, it is advisable to employ a motor-driven cream separator and also a milking machine. For the driving of the milking machine 2 to 3 h.p. is required. In these days, milking machines have proved a very valuable asset to the farmer and, where run under the direct supervision of the farmer or his son, are highly successful; and any complaints that arise as to the ineffective operation of these machines will nearly always be found to be due to the fact that they are in the charge of cowmen who do not take any interest in their operation. Over 9 000 farms in New Zealand employ milking machines. The milking load comes on very early in the morning and again in the afternoon. The preparation of food for the live stock is usually carried out in the morning. If a thrashing machine and also a hay and straw transporter and elevator are added to the above equipment, there will be a fairly heavy load for 12 hours each day during the winter. In addition, electric lighting will be needed in the early morning hours and again at night. At the hay- and corn-harvest periods, the driving of the barn machinery would be replaced by the operation of an electric fan for curing the hay and sheaves of corn, also for elevating hay and silage crops; in addition a chaffing machine would have to be driven for cutting silage. If a number of sheep were kept, an electric shearing machine should be employed. In fact, once electric power is available, its use will extend in many directions as indicated in Table 1. Among the uses on the land that should be seriously considered nowadays are electric ploughing and cultivation, electro-culture of growing crops, and electric treatment of silage. After all, the requirements of each farm have to be specially studied, as the form of farming so often differs, as does also the arrangement of the buildings.

Sizes of motors required.—On a small farm of under 150 acres the barn machinery required can usually be driven by a 1-h.p. motor. However, for the chaffing machine it is preferable to employ 3-h.p. motors, as this size would do the work more quickly and also provide an ample margin for the counter-shaft losses. On a farm of 150 to 300 acres a 5-h.p. electric motor is most suitable, as the barn machinery on these farms is slightly larger. On farms of over 300 acres at least 15-h.p. motors are required, as still heavier machinery has to be driven, inclusive of a full-size thrashing set. The latter in itself requires about 12½ h.p., and in addition a small margin is required for employing a small trusser and possibly a feeder in conjunction with the thrasher. Where the electric drive is available on the larger farms, it will also be found advisable to incorporate with the chaffer a cyclone dust-extractor.

Note.—A very good estimate can be formed of the power necessary to drive a machine, by substituting a ¼- to 2-h.p. motor for a man or two men, or replacing a horse or two horses by one 5-h.p. motor.

TABLE 2.
SIZE OF MOTORS REQUIRED ON FARMS.
Individual Drives.

	Size of motors		
	Smallest	Largest	Usual size
	h.p.	h.p.	h.p.
Book-keeping ("Auto-Count-ancy")	1/30	1/30	1/30
Cart loader	3	5	3
Cattle-cake breakers	¼	2	1
Centrifugal fat-testers	⅛	⅛	⅛
Chaffing machines	2	10	3
Cheese-curd breakers	½	1	½
Cyclone chaff dust-extractor	1	3	2
Milk-churn transporters and elevators	½	2	½
Churns for butter	⅛	5	⅛
Cider mills	2	5	2½
Clippers for sheep and horses	½	1	½
Clover cutters	¼	½	½
Concrete mixers	2	10	5
Cord wood or firewood saws	3	10	5
Corn maize shellers (single hole)	¾	1½	1
Cream separators	1/10	1½	⅛
Emery wheels	¼	1¼	¼
Ensilage cutters	10	30	15
Fanning mills or winnowers	¼	¼	¼
Feed grinders (large)	10	30	15
Feed grinders (small)	3	10	5
Grain elevators	½	5	3
Grain graders	¼	¼	¼
Grindstones	⅛	¼	¼
Groomers (revolving)	1	2	1
Groomers (vacuum)	1	3	2
Hay balers	3	25	7½
Hay hoists	3	15	5
Huskers for indian corn (maize)	10	20	15
Milk-bottle cleaners	⅛	1	⅙
Milk-bottle fillers	⅛	5	1
Milk clarifiers or centrifuges	3	10	5
Milking machines	2	5	3
Mixing machines	½	5	2
Oat crushers	2	10	5
Ploughs (electric)	12	150	60
Refrigerating machines	½	25	3–5
Root cutters, slicers and pulpers	1	5	2
Saw bench for firewood	3	10	5
Saw mills	10	50	15
Shellers for corn (maize)	10	15	15
Shredders and huskers for maize	10	20	15
Thrashers, 54-in. drum (or 19-in. cylinder)	12	18	15
Thrashers, ditto, with baler	25	40	30
Thrashers, 32-in. cylinder	30	50	40
Water pumps and liquid-manure pumps	½	5	2
Winches and hoists	1	10	3
Wood splitters	1	4	2

Water Supply Required on a Farm.

25 gallons per person per day.
20–30 gallons per dairy cow per day.
8–12 gallons per horse or cow per day.
1–2 gallons per sheep or pig per day.

Portable Motors.

With a view to the elimination of counter-shaft drives and also to enable each piece of barn machinery to be placed in the position where it is most convenient for it to do its work, portable electric motors are having

Table 3.

Approximate Output of Some Typical Electric Motor-driven Farm Machines.

Machine	Work done per hour	Speed of machine pulley	Size of motor	Work done per kWh consumed
		r.p.m.	h.p.	
Cake-breaker	13 cwts.	140	1	$1\frac{1}{4}$ tons
Chaffing machine	3 tons	300	10	0·5 ton
Churn for butter (with butter worker)	170 lb.	30	2	165 lb.
Clipper (horse)	1–2 horses	1 300	$\frac{1}{2}$	3–4 horses
Clover cutter	50 lb.	1 800	$\frac{1}{2}$	115 lb.
Corn (maize) sheller	26 bushels	280	1	36 bushels
Cream separator	135 galls.	650 (bowl, 6 000)	$1\frac{1}{2}$	260 galls.
Ensilage cutter (rye)	5·5 tons	300	10	0·66 ton
Feed grinder	40 bushels	1 800	25	3·3 bushels
Grain elevator	—	—	—	450 bushels raised 19 feet
Groomer	6–7 horses	1 300	1	9 horses
Harvester and binder	2 acres	360	$1\frac{1}{2}$ (for knife and binding mechanism)	1·5 acres
Hay curing	—	—	2·5	2 cwts.
Hay transporter	5–6 tons	35	10	0·5 ton
Milking machines	90 cows	42 pulsations, central pump 390 r.p.m.	3	52 cows
Oat crusher	50 bushels	500	2	22 bushels
Plough (electric)	0·9 acre 12-in. furrows, average land	—	60	160 sq. yds.
Root cutters	6 tons	150	2	6 tons
Shredders and huskers (maize)	2 tons	—	12	0·19 ton
Thrasher	150 bushels	1 200	15	7·7 bushels

An air-pressure tank system for the supply of the water will be found to be the most efficacious. The chief data for this system are as follows :—

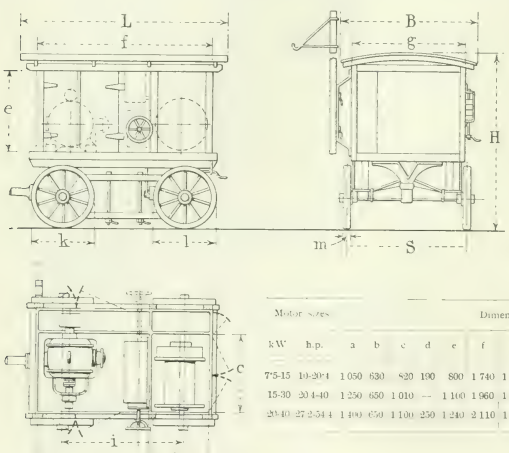
Depth of well	Size of pump required	Water delivered per hour	Pressure storage tank
ft.	h.p.	gals.	gals.
1–25	$\frac{1}{6}$	150	50
1–25	$\frac{1}{8}$	100	40
1–25	$\frac{1}{2}$	360	200
22–50	$\frac{1}{2}$	150	100
50–600	$\frac{3}{4}$–3	200–1 500	1 500

a considerable vogue. Their use certainly reduces the number of motors necessary on a farm and also the capital invested. However, it is a moot point as to whether in the course of the year's use the value of the time lost in adjusting and fixing them would not pay the interest and depreciation on a direct-connected motor. Considerable difficulty is often experienced with the installation of a suitable counter-shaft drive, owing to the fact that it has often to be placed in somewhat antiquated buildings. On some of the more up-to-date farms, counter-shafts fitted with ball bearings are employed, and arranged for self-alignment. While the counter-shaft arrangement is a simple and convenient device, the author has discovered that it is extremely difficult to get farm labourers to carry out such a simple task as keeping the belts in order. This trouble is aggravated by the fact that the machines are not in constant daily use. Where counter-shaft drives are

employed on farms, it would be a good plan to mount the driven machines on slide-rails, like those used for an electric motor, as this would save much belt trouble.

Portable motors have, however, one great point in their favour, i.e. they enable new drives to be tried and experimented upon in cases of doubt. For work outside the farm buildings they are often invaluable, and are a most useful addition even when the main drives are fixed.

Portable motors for use on farms should preferably be provided with starting switches and fuses or circuit breakers mounted on the side of the motor frame. The flexible leads from the source of supply should form a cable in which an extra earthing wire is included. A dust-protecting cover, either of metal or asbestos-lined wood. If not protected by a cover, the motor should be supplied with a shaped tarpaulin cover which can be thrown over it when not in use. Small motors complete with starters and flexible cable can be obtained ready mounted on handled bars, enabling them to be carried from place to place by a couple of men; alternatively the motors are mounted on timber skid frames or on wheeled frames, on which they can be drawn into convenient positions, being ready for service in their new location as soon as the belt is attached. Continental practice favours very substantial 3-point suspension, horse-drawn enclosed vans, for motors of 15 to 40 h.p. (see Fig. 1). For smaller motors, the author advocates



List of motors

r.p.m.	kW	h.p.
1 500	7·5	10
1 000	7·5	10·2
1 500	10	13·6
1 000	10	13·6
1 500	12·6	17
1 000	12·5	17
1 500	15	20·4
1 000	15	20·4
1 500	20	27·2
1 000	20	27·2
1 500	25	34
1 000	25	34
1 500	30	40·8
1 500	40	54·4
1 000	25	27·2
1 000	30	40·8

Motor sizes		Dimensions (in millimetres)													
kW	h.p.	a	b	c	d	e	f	g	i	k	l	m	H	L	S	B
7·5-15	10-20·4	1 050	630	820	190	800	1 740	1 190	1 185	650	650	65	1 800	2 050	1 335	1 450
15-30	20·4-40	1 250	650	1 010	—	1 160	1 960	1 050	1 350	700	700	85	2 150	2 300	1 335	1 300
20-40	27·2-54·4	1 400	650	1 100	250	1 240	2 110	1 570	1 485	700	750	100	2 400	2 500	1 335	1 850

FIG. 1.—Portable motor wagons.

convenient standard length of cable is 40 ft. If a longer length is necessary, a light wooden reel should be supplied upon which to coil any excess length not in use. A double-width pulley should be fitted on the motor spindle, i.e. the type of pulley usually employed for driving on to fast and loose pulleys. The reason for this is that the alignment of the portable motor may be quickly made, since the setting need not be so exact with a wider pulley as with an ordinary pulley. The motors should preferably be of drip-proof type. This is a more economical form of motor than the totally enclosed type, and yet it has a good deal of protection from the droppings of water, artificial manures, etc., to which farm motors are so liable. If the motor is of the ordinary open type it should be provided with a wooden platforms, suitable for use with transporter or lifting trucks, as employed under modern factory conditions. This is a very simple and effective means of mounting a motor so as to make it easily transportable at a minimum cost. This type of platform is made with legs or side supports, so that the transporter or lifting truck can be pushed underneath it when it is required to move the motor to another place. These trucks are so designed that by operating the draw-bar handle up and down the chassis rises and so lifts the load. When the load is transported to its desired situation the raised portion of the chassis of the truck is lowered until the wooden platform rests on the ground, when the truck can be removed to do other work. These trucks will be found very useful for many

purposes on a farm, besides moving portable motors. As a modification of the above scheme, where it is not considered desirable to acquire a transporter truck, the author has employed a similar frame, but fitted with 4 crowbar-operated lifting cam-legs. A crowbar is inserted in the hole provided in each leg, and they are levered up in turn. A piano-removal trolley is then placed underneath the frame, and the frame is subsequently lowered on to it by aid of the crowbar. It is then ready for transport.

Conclusion.

This paper is intended only to sum up the present position of a comparatively new development of the use of electricity. The problem to be solved is not an easy one; many minds are, however, now dealing with it and much encouraging progress has already been made. The satisfactory solution of the various phases of the problem is not merely a question of assisting a particular industry, viz. farming, but is rather a matter of benefiting mankind as a whole, for all are dependent ultimately upon the success of the farmer in his key industry to the wealth and well-being of the world. Some of the more interesting details of the more important uses of electricity applied to agriculture are given in an Appendix to the paper. This Appendix, coupled with the paper, will indicate that scientific electro-farming is one of the chief factors in furthering the world's progress.

APPENDIX.

Electricity in Farm Buildings.

The employment of electric light in place of other illuminants unquestionably adds very greatly to the safety and convenience of work in such places as barns, byres, stables and yards where there is so much hay, straw and other inflammable material. But there are many other incidental advantages, a few of which are indicated below.

The author's experience on his own farm has shown that since installing electric light in the cow byres, milk loss due to spilling has practically stopped. In fact, the value of the milk so saved is more than sufficient to pay (at 4d. per kWh) for the current consumed.

It has been discovered by experiment that certain animals, e.g. lambs and other stock, can be brought to an earlier maturity by carrying on the feeding for a few hours after sunset and also for a few hours before sunrise, in the winter time in northern climates. Electric lighting is also being used very successfully in poultry laying-houses, with the object and result of increasing the egg production during the winter months, when eggs fetch the highest prices. Careful investigation seems to indicate that the hens do not lay more eggs per annum, but by the use of electric lighting, and consequent longer hours of feeding, it has been conclusively shown that more eggs are produced at the time they are most in demand. From tests which have been made it would appear that 10 per cent more eggs can be obtained during the winter months. In the case of the lighter breeds, such as White Leghorns, the increase may be up to 25 per cent. It should be noted that the cost of supplying electric light from 6 a.m. to dawn and from dusk to 9 p.m. is only ¾d. per bird per year (or less than the value of one extra egg per bird).

In the installation of the necessary wiring it is preferable to employ chiefly either twin lead-covered or special twin tough-rubber-protected cable of the type known as cab-tyre-sheathed, on account of the deleterious effects encountered in farm buildings, arising chiefly from ammonical and acid fumes. In fact, the general system of wiring should be similar to that used in chemical factories. For the same reason the fittings should preferably be of the all-porcelain type which, after the connections are made, can be sealed up to prevent ingress of moisture, etc. In Germany bare wires mounted on insulators are employed in the cow byres.

The main supply service should preferably be run in heavy galvanized-steel conduit on the outside of the walls of the buildings, especially in cases where the roofs of the buildings are thatched. From this main distribution circuit branches can be taken through the walls for each interior group of lights as required. An excellent plan is to make the main service a bare-wire overhead distribution on high posts.

As supplied or generated on a farm, the cost of electricity is bound to be slightly higher than in dense centres of population; hence economy in the use of electricity for lighting is certainly of importance. Expenditure on suitable reflectors is therefore fully justified. The kind which should be employed is one having that approximately parabolic reflecting surface, known as the distributing or extensive type, and suitable for a 40-watt metal-filament lamp. For milking byres it should be suspended 8 ft. above the floor. This will result in an illumination of nearly 0·75 foot-candle over 260 square feet (i.e. a square of just over 16 ft. by 16 ft.). The next adjacent lamp should be placed 16 ft. away. While 0·75 foot-candle is suggested for the farm buildings, four or five times this illumination is recommended for the living rooms of the farm house.

Sterilization of milk.—Various electrical methods have been employed to obtain sterile milk. These means include the passing of a high-tension current through the milk, but this is obviously dangerous under commercial conditions. Another way is to expose the milk to ultra-violet rays while passing over a capillary cooler. As these rays undoubtedly produce ozone, the author has experimented with the discharge of ozonized air over the surface of the usual capillary cooler. Ozone of course has a deleterious action on the milk if it actually passes through it.

None of these methods is entirely successful; however, the question has arisen as to whether absolutely sterile milk is of advantage to anyone except the trader. Even the retailer may be tempted to keep sterile milk longer than he should. So possibly sterile milk is a mixed blessing. Bacteriologists seem to be of the opinion that it is preferable that the milk should not be quite sterile. Commercial interests in the steriliza-

tion of milk are undoubtedly aiming at obtaining milk that will not turn sour too quickly. This aim can be effectually attained by great cleanliness in the milking of the cows and then by cooling or preferably chilling the milk directly it comes from the cow. This can best be accomplished by the employment of a capillary cooler of which the lower portion is cooled by the circulation of brine from an electrically-operated refrigerating machine. Such milk when placed in sterile sealed bottles will not turn sour for from 10 to 20 days.

Incubators.—Owing to the practically constant voltage of the normal electricity supply, the temperature of incubators can be regulated more accurately by the aid of electric heaters than by any other means. The usual control medium is adopted, viz. an ether wafer, which consists of a hollow metal expansion disc, several inches in diameter, filled with ether, only instead of this wafer being used to operate levers to change the draught in an oil lamp or anthracite stove chimney, it is adapted to adjust a resistance in series with the heater coils.

The greatest advance in incubator construction is, however, the employment of electric fans for thoroughly circulating the air inside the apparatus. The warmed air reaches every part of the egg chamber, keeping it all at the exact temperature which is known to be the best for satisfactory incubation—in fact this system ensures that exact temperature for every egg in the incubator which is seldom approximated to in any incubator of the single-tray type.

A supply of fresh air is drawn from outside the incubator through carefully adjusted openings located around the fans. The fans are placed at the top of the heating chamber with the spindle in a vertical position, so that the fan blades can force the air downward through the heater coils into the incubation chambers, and thence upward through the egg trays, which are placed in 5 to 10 tiers one above the other. Outlets provided in the top of the incubator above the egg trays allow a certain portion of the air to escape, fresh air being drawn from the room. This system overcomes the difficulty of securing ventilation without excessive evaporation, which is a common defect in most incubators. For successful incubator practice, the three vital factors, viz. heat, ventilation and moisture, must be automatically held in correct balance.

An electric fan-operated incubator occupies a comparatively small space, 8 ft. 6 in. square × 8 ft. 8 in. high, being sufficient for a capacity of 10 000 eggs; or a space 5 ft. × 5 ft. × 32 in. deep is sufficient for 2 240 eggs. Mammoth incubators of the same capacity on ordinary lines would require 7 times the floor space and, consequently, much larger buildings.

The relative simplicity and reliability of the electric fan system, compared with ordinary methods, may be gauged from the fact that with the former, one regulator and two thermometers are required for a 10 000-egg incubator, as against 74 or more regulators and a similar number of thermometers necessary with the ordinary mammoth incubator. Moreover, the electric fan-operated incubator permits continuous factory-like hatching. On every Tuesday, say, a fresh lot of eggs is put in the incubator and at the same time live chickens are removed from the bottom trays. The percentage of fertile eggs hatched is higher than is obtained in natural or other artificial processes; the author has averaged 83·5 per cent with a 2 240-egg incubator—the first and only one so far in this country. Above all, the chicks are healthier and stronger.

Eggs incubated in machines of the ordinary type have to be taken out of the apparatus and cooled once or twice every 24 hours, but under the electric fan system the eggs require absolutely no cooling. A 60-egg incubator of the ordinary pattern but electrically heated takes 11 kWh to hatch out, while a similar apparatus but containing 250 eggs consumes 16 kWh, i.e. the larger the incubator the lower the consumption per egg.

Hovers and foster-mothers.—To all practical intents, the only difference between electric heating and ordinary heating is the substitution of a resistance for a lamp. As a rule this class of apparatus is provided with a central-heating oil lamp. This source of heat is placed in the centre of a space the corners of which are well rounded. Apart from the well-known troubles associated with oil lamps, it will readily be appreciated that the maximum number of chicks that can be dealt with is less than 100. The demand for rearing chicks on a commercial scale has led to the design of anthracite-stove-heated compartments for 500 chicks. Recently, however, experiments have been made in California with electric heaters placed round the circumference of a fair-sized room, holding 1 000 or more chicks. This is done with the idea of avoiding overcrowding of the chicks, which so often occurs with a central source of heat, and results in the suffocation of the weak and overheating of all, and if, subsequently, overheated birds get into a draught they are liable to catch chills, which in many cases cause death. A large-scale commercial brooder house in this country recently designed by the author comprises 42 compartments, each holding 75 chicks. A hot-water-heated air radiator is placed in the centre of each. These radiators are now being adapted for conversion into electric heaters.

High-tension electrical treatment.—This is entirely in the experimental stage at the moment, and no definite results are available. The general idea is to produce a high-tension discharge by means of a fine distribution wire above young chicks and also laying birds. This treatment is given for an hour or so each day and seems to brace up and stimulate the birds. It appears probable that any good effects are due to the purification of the air in the brooder or laying houses, resulting from the production of ozone in the corona discharge. It is also quite possible that it assists the birds to relieve themselves of any pests.

Testing eggs.—An electric lamp is, of course, ideal for this purpose as it is so easily switched on and provides such a powerful source of light.

Wireless telegraphy and telephony.—Two types of wireless weather messages are at present issued each day by the Meteorological Office:—

(*a*) A general inference containing a forecast of anticipated weather for the British Isles, issued at 9.15 a.m. and 8 p.m.

(*b*) Synoptic messages containing coded weather reports from 17 stations in the British Isles, issued at 2 a.m., 6 a.m., 8 a.m., 2 p.m. and 7 p.m.

All the above issues are made on 1400 m wavelength continuous waves, the call sign being GFA. It is proposed in the near future to issue district fore-

In the near future, where sufficient water is available, electric pumping will undoubtedly be used on farms for irrigation in seasons of low rainfall. Thus the farmer will have yet another aid in circumventing the weather and will be able to adjust the supply of water to the needs of the crop. Only by electric pumping is such a scheme, desirable as it is in itself, a commercially possible project.

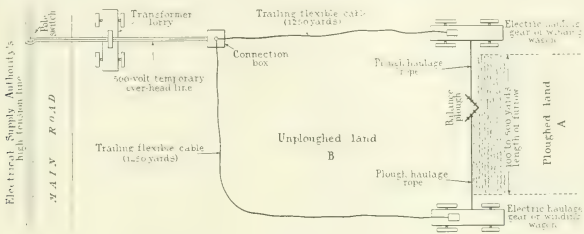


FIG. 2.—Electric ploughing on the double-winder or Fowler steam 2-cable system.

casts by wireless telegraphy, in addition to the general inference mentioned above. In order to reduce the length of the messages, these will be issued in a simple code, copies of which will be available for distribution to those interested. The Meteorological Office hope that these forecasts will be of considerable use to farmers who may have access to a small wireless receiving set. Careful consideration is being given to the matter of issuing the forecasts by wireless telephony.

Experience has shown that the limiting cost of irrigation per acre for general farming (not intensive) is 5s. per annum for wheat lands, and 15s. for sugar cane. Pumping costs and interest charges must not exceed these figures. The minimum water supply to irrigate 100 acres is 500–700 gallons per minute. Each irrigation varies from 2 to 6 inches deep (chiefly about 2 inches) with, say, a total of 2 ft. per acre per annum, requiring, say, 550 000 gallons per acre per

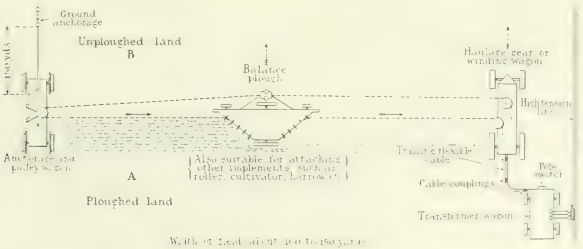


FIG. 3.—Single-winder electric ploughing system (single-cable).

USES ON THE FARM LAND.

Irrigation.—Although not a matter at present interesting the average farmer, the provision of an adequate water supply for irrigation is in many countries of great importance. Electric motors are now preferred for driving the irrigation pumps, as they allow of the plant being placed in the best position and do not require skilled and constant attention.

annum. Of the water pumped, 20 per cent will be lost by seepage and evaporation.

The principal methods of applying water to the land are :—

(1) By large diameter vertical distributing standpipes with underground feed pipes.
(2) Through portable 12-ft. galvanized light steel pipes.

(3) By blocking or checking in sections.
(4) By general flooding.
(5) By distributing the water in furrows.
(6) By spraying (with or without portable rolling pipes).

In Holland and other countries, very large electric pumping installations are now in operation for the removal of excess water. Windmills have been displaced, because when pumping is required during rainy periods there is usually no wind. An interesting development of irrigational farming is the maintenance of the water level in the fields at definite depths below the surface, in accordance with the nature of the crops. The depth of water in each field or range of fields is controlled by automatic electric pumps.

Ploughing.—This is one of the farmers' heaviest and most important jobs, and is accompanied by the usual difficulty that it is a seasonal demand. Much experimental work in electric ploughing has been carried out, but no entirely satisfactory solution has been reached. Extensive practical work in Germany, Sweden, Italy and France has sufficiently demonstrated that the results are in favour of electricity as compared with

Table 4 shows briefly the position with regard to these five systems.

TABLE 4.

System	Remarks
(*a*)	Equipment too heavy; packs the land excessively; cannot be used on soft ground
(*b*)	Heavy equipment; considerable wear on trailing cable; electric cable winding gear unsatisfactory
(*c*)	Double-rope haulage; large capital outlay; method successful on large scale; requires wide headlands, trailing distribution electric cables and 80–125 h.p.
(*d*)	This system is a compromise between systems (*c*) and (*e*)
(*e*)	Single-rope haulage; the most practical for ordinary farms; outlay reasonable; requires 12–60 h.p.; anchorage difficulties not nearly so great as with the Howard steam system

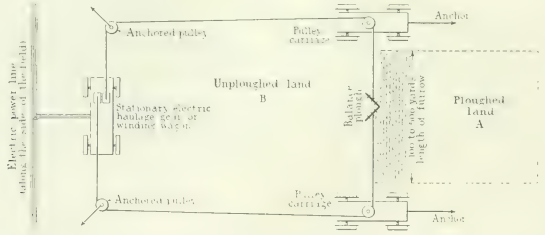


FIG. 4.—Electric ploughing on the Roundabout single-winder or Howard steam single-cable system.

animal, steam or oil ploughing tackle. The only important competitor of electricity is steam, under conditions where fields are very large, and even then the electric system has many superior advantages. In the case of small fields the electric system is undoubtedly most advantageous on account of its great economy. The systems employed so far may be summarized as belonging to one or other of the following groups :—

(*a*) An electric accumulator plough.
(*b*) An electric motor-operated plough, with a trailing supply cable.
(*c*) An electrically-hauled plough on the Fowler steam system.
(*d*) An electrically-hauled plough on a modified Fowler system with a single winder.
(*e*) An electrically-hauled plough on the Roundabout or Howard steam system.

Figs. 2, 3 and 4 illustrate the principal characteristics of each of the three last-mentioned methods.

Double-rope haulage is beyond the reach of the average farmer, as he has not sufficient land to justify the outlay for heavy plant requiring 80- to 125-h.p. motors (such sets require 6 to 8 horses to draw them into position). It is, however, well adapted for contract or co-operative work. For this purpose the author has suggested a plant for use in situations where there is no public supply of electricity. It consists of a heavy-oil generating set, of Diesel or semi-Diesel type, mounted on a lorry. This portable power station is intended to be drawn to the point on a main road nearest to the fields to be ploughed, the idea of course being that such a heavy plant could not be successfully hauled over soft or ploughed land. From this power station the electric power is transmitted by a temporary overhead line to the field to be ploughed.

A somewhat similar scheme has been put into practice in France and Germany, but substituting for the lorry power station a portable transformer house which is drawn up close to the nearest high-tension transmission

line, from whence it obtains the necessary current, transforms it to the pressure suitable for the ploughing tackle, and transmits it to the plough motor by a temporary overhead line.

As showing the modern trend of development, the electric haulage set made by the Société Générale Agricole is of special interest. A 50-h.p. petrol engine enables the set to travel from farm to farm; it also operates the plough if a supply of electricity is not available. A 125-h.p. electric motor is provided and also a portable 5 000-volt overhead transmission line 1 100 yards (say 1 km) long with two trailing cables of similar length. The steel plough ropes are each 720 yards (say 650 m) long. Each equipment is guaranteed to plough 25 000 acres (say 10 000 hectares) per season. Performance data are given below.

Results for Previously Cultivated Soil [*Minimum Furrow Length* 440 *Yards* (400 *m*)].

Depth of furrow		Work per hour		Consumption in kWh per	
in.	cm	acres	ares	acre	hectare
6	15	2·5–2·75	100–110	14	35
8½–10	22–25	1·87	75	18	45
10 plus 6 Sub-soiling	25 plus 15	1·25–1·38	50–55	36–40	90–100

The author is indebted to L. Guédeney of La Compagnie d'Enterprise Electro-Méchaniques for turning his attention to the single-rope method of ploughing which, though old from a steam-tackle point of view, is comparatively new as an electrical method.

The tackle comprises a single electric motor with two haulage-rope drums, either of which can be driven by the motor, as desired by the operator, while the other pulley pays out rope. The haulage rope is arranged by the aid of suitable pulleys to follow round the sides of the field to be ploughed. At two corners anchored angle pulleys are provided. At the other two corners stationed pulleys are mounted upon carriages. An anchor rope is taken from each of these carriages to the side of the field. When the rope is pulled by the haulage set the pulley carriages are drawn along to the extent permitted by the slack in their anchor ropes. The balance plough is attached to the haulage rope between the two pulley carriages. The method of ploughing is to haul the plough from one pulley carriage to the other. The balance plough is then turned over ready for the next set of furrows. Before starting the new run the anchor rope of the further pulley carriage is slackened out, thus permitting this carriage to advance a distance equivalent to the width of the new set of furrows. The plough is then drawn over to this further pulley carriage, and so on. Thus it will be gathered that, as the ploughing proceeds, the pulley carriages gradually approach the hauling set.

The success of such a system is naturally dependent upon attention to the details of the various portions of the equipment. The author's scheme includes the use of ball-bearings wherever possible, also intermediate supporting pulleys to take the weight of the rope off the ground. Also the pulleys are provided with removable jaws, so as to facilitate the placing of the ropes in position. The general design of the haulage gear is along the lines of a portable mining set, in which class of machine considerable experience has been gained.

The system is well adapted to small fields, as the haulage set enters only one corner of the field. Very large fields would be ploughed in several sections. Once set up in a field, two comparatively unskilled men only are required—one to operate a tram-car type electric controller, and the other to work the balance plough.

A large haulage set will plough from 19 to 20 acres per day (on an average) as compared with nearly 1 acre with horses. Electric ploughing sets can be used on much steeper ground than steam sets. Normally from 30 to 36 kWh are consumed per acre, ploughing three 12-inch furrows at once on average ground. The nature of the ground and weather conditions markedly affect the consumption.

The following results of experiments conducted by Ringelmann show the wide variation in the resistance offered by different soils:—

Soil	Resistance
	lb. per sq. ft.
Light	740–820
Heavy	1 125–1 230
Four-year lucerne ..	1 780
Heathland	1 260

The horse-power required at the plough is given by the formula

$$\text{H.P.} = Klpv/550$$

where H.P. = horse-power;
K = resistance in lb. per sq. ft. (according to soil);
p = depth of furrow, in feet;
l = width, in feet, of furrows ploughed at a time; and
v = speed of plough, in ft. per sec.

The horse-power thus obtained should be doubled to allow for stones, etc.

On electric ploughing sets two speeds are usually available, viz. 3 ft. per sec., i.e. 2 m.p.h. (say 0·9 m per sec.) and 5 ft. per sec., i.e. 3·6 m.p.h. (say 1·6 m per sec.). By a change of gear these speeds can be

increased to 4 and 7 ft. per sec., i.e. 2·9 and 4·7 m.p.h. (say 1·3 and 2·1 m per sec.).

The practical furrow length even in very large fields rarely exceeds 450 yards, chiefly owing to the difficulty of signalling.

Unfortunately, the problem of electric ploughing is not merely a matter of solving electrical difficulties. It involves also a careful consideration of the design of the implements to be employed. Though agriculture is such an ancient art, or perhaps because of this, the scientific principles of the design of even such features as ploughshares do not seem to have been as carefully investigated or mathematically analysed as they should have been. There are well over 200 varieties of plough in this country, and none of them seems very suitable for haulage at higher speeds than that of horses.

Electrical operation of harvesting machinery.—The usual principle of operation of a binder for reaping grain crops is by the traction drive of a large straked wheel (known as the bull wheel) which is the principal support of the machine. This is quite a satisfactory method for ordinary speeds under normal conditions, but the increased cost of labour and the greater value of time nowadays call for faster cutting and also the possibility of cutting any kind of crop in any sort of condition by machinery.

The use of an electric motor drive for the binder (as developed by the author) meets these requirements, and tests on binders show that the draft is lessened. As the drive is not obtained from the bull wheel the machine can be used in certain sections of the farm where wet ground has hitherto made the operation of the binder very difficult. The use of the electric motor also permits the cutting of heavy grain in a proper workmanlike way, when the binder has to be drawn at comparatively low speeds, e.g. when turning corners and the like. This is accomplished, owing to the fact that the knives or sections run at a constant speed throughout. It is this fact, coupled with the possibility of the independent control of the speed of the knives, that makes it practicable to cut heavy tangled crops that have been blown by the winds. In practice it is found that the use of electrically operated binders effects a considerable increase in the number of acres cut per day, which increase may as a minimum be anticipated to be at least from 4 to 5 more than the normal 16 acres. With the electric motor drive crops can be cut at a rate about one-third faster than the normal. Similar beneficial results are to be obtained when mowing machines are electrically equipped for cutting grass for hay.

The electric power for driving the motor is obtained from a dynamo mounted on the tractor which is hauling the binders (one to three binders are often towed by a single tractor). The electric motor (of $1\frac{1}{2}$-h.p. capacity) is of the variable-speed type, with a controller fitted in a convenient position adjacent to the seat of the driver. The motor speed must be constant, irrespective of the speed of the binder.

In America combined harvesting and thrashing machines are successfully employed in certain parts of the country. This system saves considerable time and is generally a great convenience, circumventing bad weather conditions which so often spoil a crop after cutting. In Great Britain this practice cannot be followed at present, owing to the necessity for curing the grain, which is not subjected to such powerful sunshine whilst growing. The author is, however, of the opinion that it can be accomplished, if proper drying and curing electric-fan arrangements are provided at the farm buildings. Some tests to this end have already been carried out. Obviously a combined harvester and thrasher is essentially a machine to be electrically driven.

Electro-culture.—The object of electro-culture is to increase the harvest yield by stimulating plant growth. It is very difficult to determine what increase can be obtained by electrical means, because so many natural factors, whose exact influence is still but imperfectly understood, also affect the result.

On the whole, a careful comparison of a great many experiments on large-scale conditions shows that there is undoubtedly a considerable improvement in electrically treated crops. The author has not yet personally carried out any experiments on a commercial scale, but intends to do so eventually. He has, however, taken the opportunity of investigating several experimental installations, viz. at Rothamsted, Harper-Adams College, Newport (Salop), Hereford, Chester, Dumfries, Haarlem and Lucerne; further, some 7 English installations are in operation in Germany. Experimental work is also proceeding in France, under the guidance of Dr. Heim. An analysis of the results obtained at the above installations seems to indicate that an electrically treated crop may be reckoned upon to produce at least 10 per cent more grain, accompanied with a proportionate increase in the quantity of straw.*

The cost of current is negligible, so that the problem has little interest for the electricity supply undertaking, the only desire of which is to increase its immediate sales of current. Experiments carried out at the Imperial College of Technology at South Kensington, with currents passing through the plant, showed that vegetable growth was accelerated by currents of the order of $0{\cdot}3 \times 10^{-9}$ ampere, but that the plants were injured by currents of 10×10^{-9} ampere. The chief question, therefore, that really has to be considered is the commercial one as to what amount of capital is necessary to attain this increase in the crops. The cost of stringing the wires is not at all important, for 4 or 5 lb. of fine wire (29 S.W.G.) is all that is required per acre, plus the heavier insulator-borne cable supports around the

* On February 2nd, 1918, the Board of Agriculture and Fisheries appointed a Committee to investigate the possibilities of electro-culture. This Committee has carried out experimental work and has issued three interim reports. Summarizing the results of all the field experiments since 1915, they state in their last report: "The data taken as a whole, show that of the 14 positive results of experiments extending over 6 years, only 3 are less than 10 per cent, while of the 4 negative results none reaches 10 per cent. Of the 10 positive results with spring-sown cereals only 2 are less than 10 per cent, while 6 show an increase of 30 per cent or over, while both the negative results show decreases of less than 10 per cent. The result of field experiments with these spring crops shows an average increase of 22 per cent. The effect of electrification in increasing the yield of spring-sown oats and barley has thus been demonstrated. The effect on clover-hay is probable, while that on winter-sown wheat is still uncertain."

field. The serious factor is the cost of the transforming and rectifying apparatus. At Harper-Adams College the cost of the equipment for an area of just over 2 acres was as follows:—

	£	s.	d.
Aerials	5	0	0
Insulators	11	15	0
Motor-generator	125	0	0
Transformer	200	0	0
Instruments	25	0	0
Erection, carriage, etc.	33	5	0
	400	0	0

The plant was considerably underloaded, and so could have dealt with a much larger area, with an additional cost only for aerials, insulators and their erection. The consumption was at about the rate of $1\frac{1}{2}$ kWh per acre, and electrification was carried out for 8 hours daily, i.e. 7 to 11 a.m., and 3 to 7 p.m., weather conditions permitting. The average height of the wires above the ground was 6 ft., and they were placed about 5 ft. 6 in. apart. Approximately 4 lb. of wire was required per acre. A 1-kVA oil-cooled, 25-period, singie-phase Ferranti transformer was used, as at Rothamsted. This was provided with tappings for 15 000, 30 000, 45 000 and 60 000 volts. The secondary current was from 0·066 to 0·01666 ampere. The normal voltage employed was 45 000 volts, and the current supplied did not exceed 2·6 mA per acre. The high-tension current was made unidirectional by means of a rotating Newton and Wright disc rectifier mounted on the motor-generator shaft. It is estimated that the capital cost of a 100-acre equipment would be about £4 per acre.

By deduction from the experiments which have so far been carried out, the most suitable arrangement for a commercial farm is to provide alternating-current supply; a 100 000-volt high-tension, oil-cooled transformer; and a mechanical rectifier driven by a small synchronous motor. The overhead network should be placed 15 ft. above the ground. It would probably be necessary to operate such a plant only for about an hour in the morning and again in the evening, during the spring and early summer months. The transformer would be preferably switched on and off by a time-switch. A Lodge or similar valve would probably give a more efficient discharge than a mechanical rectifier, but on large-scale work these valves do not appear to be so practicable. In the course of time it seems quite likely that the transformer may be superseded by a motor-driven influence machine. Owing to the low power factor of these installations it is necessary, before accepting the readings of any instruments, to see that due corrections have been made.

The Tesla transformer employed at Lucerne on small-scale but successful experiments was very attractive from the point of view of absence of danger of accidental shock to farm labourers or animals. The overhead wires, however, would in practice have to be placed so low as to interfere with ordinary farming operations. However, the principle of the utilization of very high-frequency currents is opposed to the British practice of low-frequency unidirectional currents and therefore would seem to require further investigation, as so much more work has been done along these lines in Great Britain. However, there are considerable differences of opinion as to methods, between the official Electro-Culture Committee appointed by the Ministry of Agriculture and what may be perhaps termed the Western commercial electro-culturists, represented by the work of Messrs. W. T. Kerr (Hereford), S. E. Britton (Chester) and C. T. Allan (South Wales Power Company), and the Agricultural Electric Discharge Company, Ltd.

An interesting feature that seems to be allied with electrical treatment is the possibility of the destruction of insect pests. This destruction is largely brought about by the fact that, in the presence of a high-tension discharge, the antennæ, wings, legs, etc., of the insects tend to rise and so become uncontrollable, causing these insects to fall helplessly to the ground.

Various theories have been put forward to account for the effects produced, e.g. that the discharge forms nitrogen compounds, ozone, etc., producing manurial or plant-feeding effects. However, the quantity of electricity used is so small that only an infinitesimal amount of manure or its equivalent could possibly be produced, even under the most favourable conditions. In fact, the best results from electrification are always obtained from the land which is richest in nitrogen. Hence the author's deduction is that it is entirely a physical, stimulative effect. This is also practically the opinion of Sir Oliver Lodge, Mr. J. E. Newman and Prof. V. H. Blackman. The last-named has carried out a great deal of experimental work on this subject, both in the laboratory and on the field on behalf of the Electro-Culture Committee of the Ministry of Agriculture. Whatever the cause the fact remains that better results *are* obtained with electrically-treated crops. Also the cost of carrying out the electrical treatment (apart from considerations of the capital required for the installation) is nominal.

The employment of short heat waves from luminous electric heater lamps has been suggested and experimented upon. However, the experiments have been on a small scale, and it would seem that the power consumption necessary is likely to be very great.

Crop Treatment

Drying of fruits and vegetables.—A drying plant is a useful form of rural industry that can be economically added to many electrically-equipped farms. Many farm products in seasons of plenty are wasted, simply because it does not pay to market them at the time. Experiments carried out by the author show that it does not pay to employ electricity as the heating medium for drying purposes. However, rubbish can be burned to provide the necessary heat, the fan being electrically driven.

It is of great importance that drying should be carried out thoroughly and uniformly. The time required for drying is very definite for a given material. In general, the majority of fruits and vegetables can

be dried at a temperature of from 120° F. to 160° F. (50° C. to 70° C.) without loss of their characteristic food qualities and flavour. The time taken to dry to 8 to 12 per cent of moisture is usually from ½ hour to 3 hours. In the ordinary system, 1 lb. of coal is usually required per 3 lb. of moisture in the fruit or vegetable. The author has successfully dried wet green grass by the aid of an electrically-driven fan alone, without auxiliary heating other than that produced by the natural heating of the rick.

Making hay.—Normally, given suitable weather conditions, there is no better way of making hay than by aid of the sun. However, in bad weather, artificial hay-making becomes a commercial proposition. A rainy period at hay time sends up prices rapidly, on account of the fear that hay will be short and poor. Hence, artificial drying is worthy of interest and all preparations should be made for carrying it out in wet seasons.

Some little time ago the author was invited by Mr. W. W. Hood, the well-known mining engineer, to take part in what proved to be a successful experiment in hay drying. This test was carried out in Scotland, where hay-making conditions may be said

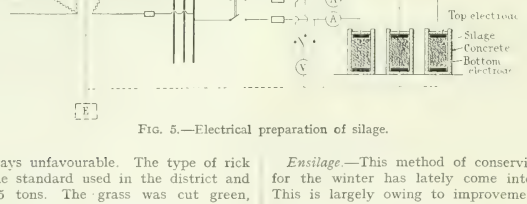


FIG. 5.—Electrical preparation of silage.

to be nearly always unfavourable. The type of rick employed was the standard used in the district and weighed about 5 tons. The grass was cut green, with the rain on it, and was immediately stacked. A wooden duct was led into the base of the stack, and air was blown through this by means of an electrically driven "plenum" fan, which absorbed 3·25 h.p. and produced a pressure of 2½ inches on the water gauge. It was found that the rate of drying was in inverse proportion to the amount of moisture suspended in the atmosphere. No drying took place when the atmosphere was saturated, though the passage of the air through the stack prevented the rick from overheating. The making of the hay in this instance occupied some 30 hours, 60 per cent of the weight of the grass having to be evaporated. The rate of evaporation was found to be at the rate of 2 oz. per 1 000 cubic feet of air per degree F. Smoke was introduced to the stack through the fan intake and appeared uniformly all over the stack, thus demonstrating the effectiveness of the simple duct.

Hay-making is not the simple operation that it appears to be. After the hay is dried it has to be cured, during which process heating occurs, due to various natural changes in the hay. A good deal of vapour is given off, together with an aromatic smell, and the hay turns a light brown colour. If the temperature is not properly controlled it increases and the nutritive value of the hay is destroyed, even if the stack is not set on fire.

Artificially-dried hay looks better, has a better aroma than naturally-dried hay, and its food or nutritive value is greater. Incidentally, when artificial drying is adopted, the process can be made continuous instead of necessitating the concentration of a large amount of labour for a relatively short period.

On the Continent F. Ringwald has successfully dried hay in the hay wagons, before transport from the fields to the barns. For this purpose a duct, provided with vertical, galvanized sheet-metal standpipes, is placed ready in the bottom of the cart before loading.

If the hay-drying apparatus be combined with auxiliary arrangements for drying fruit, vegetables, hops, etc., it becomes a paying proposition for any farm, even when it is not used for hay-drying in favourable sunny seasons.

Hay being a bulky and cheap substance, the cost of handling must be reduced to a minimum.

Ensilage.—This method of conserving green fodder for the winter has lately come into extended use. This is largely owing to improvements in silos, for when previously tried some 40 years ago, pits were utilized which only too often produced sour silage. This led to the abandonment of the practice. The latest development is electrical silage, of which there are already nearly 100 examples in Germany. It is claimed that by this method the fodder is better preserved, as objectionable bacterial action is arrested before it has time to do any damage. The general arrangement is quite simple, as indicated in Fig. 5. Each silo has an earthed electrode fixed at the bottom, and a live electrode is placed on top of the freshly-cut green-stuff, when the silo is filled. Up to 10 kVA is required for a silo of about 20 ft. (6 m) in height and 14 ft. (4·25 m) in diameter, and the time required is 24 to 48 hours. Ten tons of fodder require between 130 and 200 kWh.

Accounts.—The commercial test of any improved method is the financial result, and this can be shown accurately only by the aid of proper account books. An ordinary farm cannot afford large book-keepers' salaries, and accordingly the author devised a semi-automatic system for keeping and analysing his own

accounts, as it was very essential to keep accurate accounts on a farm where new methods were being applied. This system, which has been named the "Auto-Countancy" system, would, although originated for farmers, also be a boon to all small professional and business offices. It is a double-entry method, which does not depart in any feature from the accepted principles of modern efficient book-keeping. The "Auto-Countancy" system is preferably carried out with the aid of an electrically-operated book-keeping machine, adapted by the author from the now familiar cash register of the shop-keeper (the ordinary cash register is, of course, merely a single-entry device). These machines are costly, but they can be purchased for a sum not exceeding the salary of a good clerk for a year. It may perhaps be mentioned in passing that the "Auto-Countancy" system can be worked very effectively, but not so quickly or with so little trouble as regards accuracy, without an electric machine at all.

Not only are proper ledger accounts kept by this method, but also the analyses of the costs of any department of the farm are rendered available, whilst at the same time the services of skilled clerks are dispensed with. Every account, whether "out" or "in," is entered on slips of paper in quadruplicate. These slips are then inserted in a mechanical file or pasted into a set of loose-leaf books, if so preferred, in accordance with their classifications. This placing of slips substitutes the usual posting of separate entries by the pen of a clerk, and mistakes due to copying are avoided. Further, no particular skill or knowledge of book-keeping is required, while a trial balance of the whole business can be read off at any moment. This is due to the fact that all accounts are kept simultaneously. Hence, account-keeping by electricity has much to commend it to the farmer. A suitable electric machine would consume about 2 kWh per annum; the size of motor required is only $\frac{1}{32}$ h.p.

Discussion at The Institution, 30 March, 1922.

Mr. Ll. B. Atkinson: The paper hardly lends itself to the kind of critical discussion that is usual at this Institution, because the author—and I think it is a very valuable feature of his paper—has given us the information which he has collected together both from work he has been carrying on for some years and from the work of others in all parts of the world. I have had the pleasure of seeing a good deal of the work which the author has been doing in its experimental stages, and it is only fair to recognize that the matter is still entirely in an experimental stage. The chief object of bringing the subject now before the Institution is in order that a great many electrical minds may be brought to bear upon the problem, so that other men, each in his own way, may aid in the solution of the problems which, as the author has explained, still exist; in fact they nearly all still exist. I therefore think that the best thing to do in this discussion is to try to add to what the author has told us, each from his own experience or his own point of view. It is well that at the outset one should realize some of the difficulties and disadvantages that arise in the applications of electrical machinery to agricultural problems. The chief disadvantages are, first, the very small output which is obtained (measured in pounds sterling) from an acre of land, and secondly, the very small period in any given year during which any machinery can work. Agriculture has experienced very violent oscillations since 1914, and therefore we must confine ourselves to some particular period. My remarks and the few figures that I shall give will be based on the 7 years immediately prior to 1914. Since then almost any result can be produced, but it must be assumed that we shall settle down at some time in the near future approximately to those figures. I have said that the first of the disadvantages is the small output that can be obtained from the land. The output in this country, taking the ordinary 4-course rotation, for the 7 years before 1914 was on the average about £5 15s. per acre. The author has given a figure dividing up the farms in this country into large and small ones, and he has shown that by far the greater proportion of the farms of the country are under 150 acres in extent, so that for the moment I shall speak of 150-acre farms. The average output of such a farm—I am speaking now not of specialities or cattle or pigs fed on purchased foods, but of actual agricultural produce from the land—will be worth somewhere between £750 and £1 000 only. The next point to consider is the small period during which most of the apparatus or machinery can be used. The author has shown cinematograph films of thrashing machines at work. He has very properly said that the future of electrically driven machines owned by farmers may be in the direction of smaller machines working for longer hours, but if we take a 150-acre farm the ordinary thrashing set which comes on to it will do all the thrashing that is required for a year in about 30 hours; so that such machinery will be worked for only 30 hours per year. The use of machinery for such short periods per year is something of which we electrical engineers have no experience, and it is well that we should recognize that these are the sorts of problems that have to be faced in agriculture. Let us study this 150-acre farm first from the point of view of the supply undertaking, and secondly from the point of view of the farmer who has to buy and use the electric current. The author has stated that he considers that the maximum demand, leaving out of consideration the bigger works of ploughing which he has illustrated in the later slides and films and which at the present moment are quite impossible on a 150-acre farm, is about 3 kW and that the consumption on the farm buildings would be about 1 500 kWh per year. That is equivalent to about $1\frac{1}{2}$ hours' use of the maximum load per day, or $4\frac{1}{2}$ kWh per day. Now we come to the cost at which that current will be supplied or at which it will be used. We must not forget that for those smaller operations, i.e., chaff-cutting, root-slicing, cake-breaking, churning, etc., there is a competitor in the small petrol or paraffin engine.

Such engines are very largely used not only in this country but all over the world, and on these smaller farms the competition will lie between the use of such petrol engines or paraffin engines and the electric motors which have been shown on the lantern slides. The equivalent cost of such a petrol engine for 1 kWh of electricity is roughly about that of a pint of paraffin and some lubricating oil. In other words, except for the greater convenience of electricity and the fact that much less expert labour will generally be able to handle motors than to operate paraffin engines, the comparison is between 1 kWh of electricity and a pint of oil, which to-day costs about 2½d. If that were the final figure—the author's figure is 4d.—it would mean that the consumption on a 150-acre farm would be about £16 per year. That is the amount that the supply undertaking might expect to receive; and if that has to be supplied at 2½d., which is the figure I have arrived at as the competitive price with the paraffin engine, it must be carried to the farm and into the motor at 2½d. per kWh. Supposing it costs 1d. at the generating station, that allows 1·5d. to the supplier to get it on to the farm. If the problem be studied from that point of view it will be found that on a basis of 13 per cent per annum interest and depreciation the supply undertaking cannot afford more than £73 to convey the supply to the 150-acre farm, and it will prove to be very difficult to do so for this sum. If we take the author's figure of 4d., which I think is a very reasonable figure and one which most agriculturists would willingly pay, the comparison is rather better. A sum of £150 would be available as the possible capital outlay on the part of the supplier to bring the electricity up to the farm, and he would in that case receive about £30 or £40 instead of £16 a year. That is the supply side of the question; that is the problem which the supply undertaker who contemplates this distribution to small farms has to solve. I will now turn for a moment to the problem as it would appeal to the man who is working on the farm. Taking the average figures which were given in evidence before the Agricultural Commission, 1919, the average total cost per acre was £4 19s. 3d. per year. That was the total expenditure in cultivating an acre of ground which produced a result of £5 14s. 5d.; in other words there was a margin of 15s. 2d. per acre. It is generally considered that farming is a highly profitable and even almost an easy job, but if it were realized that the farmer in 1914 was making on the average about 15s. per acre after paying interest on capital, etc., probably a different opinion would be held. The man with a 150-acre farm would therefore be earning £112 a year for his own wages and as a remuneration for his intelligence. I need hardly say that a man who is earning only £112 a year has to look very carefully at his future outlay in order to see what benefit he is likely to obtain from it. Of the sum of £4 19s. 3d. mentioned above, £1 11s. 7d. is paid away in wages, and the remainder of the charges relate to things that would not be affected by electricity as a motive power. The wages of about 3 men at £1 11s. 7d. per acre amount to £250 a year. Now another common difficulty in farming is met with, i.e. that the number of men on such a farm is so small that unless one man can be dispensed with at once there is not much achieved. I estimate that the annual reduction in work that would arise from using motive power, exclusive of ploughing and field operations not yet practicable, whether it came from an electric motor or from a petrol motor on a farm, would be only of the order of one-half of one man. On such a farm, therefore, unless other earning work can be found for that half man's time no benefit has been gained. It is for that reason that, without wishing at this juncture to say that I am discouraging the use of electricity on small farms, I should like to emphasize the point that the majority of farms in this country are of a size where the use of motive power will not achieve very large savings or very greatly increased production. It is for that reason that I would rather lay stress on a part of the paper in which the author refers to the fact that he has not yet experimented much on the question of electro-culture, although he says he hopes to do so. The Reports of the Electro-Culture Committee have quite definitely established, at least as regards certain crops, more particularly spring-sown corn crops, that an increase of about 30 per cent, both of grain and of straw, can be produced. Referring back to our initial figure of a 150-acre farm producing £5 15s. per acre, if we can add 30 per cent to that figure we are adding something like £1 16s. to the margin per acre, which was only 15s. It appears to me that there is much more to be hoped for from carrying on experimental work in that direction, viz. in augmenting what I call this miserable output from the land so as to get the margin in an increased product, than in trying to reduce the amount of labour. The possible increase of margin of profit is something like 6 times that arising from the possible saving on such a farm by the use of electricity as motive power. The author has given some information on the subject, but the small farmer on a 150-acre farm earning £112 a year might gain something like £200 by augmenting the output of the farm. I do not see, however, how he will ever gain more than £40 by the uses of motive power to which the author has referred. We must recognize, however, that the consumption of electricity for electro-culture processes is so small that no supply undertaking will want to be troubled with it. I think, therefore, that evolution must proceed on these lines. All these things have be experimented with. The possibilities of increased crops through the use of electro-culture is what will tempt the moderate-sized farmer to use electricity. He will use electricity and get these savings in labour by the use of this motive power, but the real inducement to the farmer will be, I believe, in the augmented crops resulting from electro-culture. That, I think, is what is likely to happen to the enormous number of 150-acre farms in this country.

Mr. B. M. Jenkin: My remarks will be rather from the farmer's point of view than from that of the engineer. Although I am only just out of my apprenticeship as a farmer—7 years is not too long an apprenticeship for such a difficult job—I hope that I may be able to say something to indicate what we have to consider before we rashly embark upon supplying electric power to farmers. Before we consider its application I think we ought to study the nature of the work that has to be done and how far it is possible to use electrical power on a farm. In order to do so we must take into consideration the

old method of farming with horses, and make a comparison between that method and the author's suggested method. I propose to deal rather with a 300-acre than a 600-acre farm, because my own farm is about that size and it is easier for me to make the comparison. To begin with, assuming that about half the farm, or 150 acres, is arable, ploughed land, and taking the unit of power as 2 horses drawing the plough and other implements, those 2 horses in ploughing the land and cultivating it will take about 100 working days during the autumn and winter. Of course, 2 horses only will not do it; several teams will be necessary, but it is 100 days' work for 2 horses. The other cultivations, including harrowing and drilling during the 6 winter months, will amount to about another 180 days, making a total of 280 working days. Those horses will travel in a day's work roughly 10 miles, so that they would travel some 2 800 miles in drawing implements over the land. The number of times that the land has to be traversed in simply ploughing, sowing and cultivating the growing crop is about 6 or 8 at least, with different implements, for one crop, not including harvesting. In addition there will be a good deal of idle travelling, amounting to, say, 200 miles in going to and coming from the work, so that the horses have roughly 3 000 miles to travel during the winter months. Now we come to hay making. For a farm of that size there will be about 14 days for cutting and making the hay. Cutting the silage crop will take about 4 days and the cutting and binding of the corn perhaps another 12 days. Those are the main times that the implements will have to be moved about the land. The next important point is the question of transport. It can be assumed that on a 300-acre farm if everything is brought from the fields to the farm buildings it will have to come about half a mile. First of all about 50 tons of hay will have to be carried. The silage would amount to 120 tons; there will be 250 tons of corn to carry and about another 250 tons of roots. Then perhaps 450 tons of manure will have to be carted from the yards to the fields. Also, in connection with the marketing of the produce on a mixed farm, roughly about 100 tons of produce will have to be carted away from the farm to the railway station. The artificial manures and coal and feeding stuffs will probably weigh 75 tons, and will have to be conveyed from the station to the farm. If all that is done with one pair of horses on a 300-acre farm it will be found that those two horses walking side by side hauling implements, waggons, etc., and transporting material travel altogether about 4 000 miles, and in addition they have to haul empty waggons and carts 1 000 miles in the year. The total weight to be transported amounts to about 1 200 tons, equivalent to 1 000 ton-miles under the conditions assumed. Now let us consider how far electricity is adapted for that purpose. At present horses supply the power: can we substitute electricity to do that work? It seems to me that electricity is eminently unsuited for it. The separate fields will be about 10 acres in size. That is a convenient unit of size, because a great many operations can be carried out so as to finish a field of about 10 acres in a day. One field of 10 acres can be ploughed by horses in 10 days if the weather allows. Then the horses have to move somewhere else, to another of the 15 arable fields perhaps at the other end of the farm. They are perpetually moving about over the farm which has an area of about $\frac{1}{2}$ square mile, applying the power at different points as required throughout the farm. With regard to the question of using electric power for that purpose, the first difficulty is a distribution system that will carry current to each of those 15 fields. Next, the work of ploughing cannot be started by the apparatus described by the author until these anchors, the motor and pulley carriages and the plough have been hauled on to the fields. That haulage is apparently done by horses, as the apparatus is not self propelling. It would take, I should say, about 2 days and many men to set all that gear up, to run the cables out, to fix the anchors and to get to work. Then when the field is finished in about 2 days the apparatus has to be taken up, carried away and put down somewhere else to do another 2 days' work. Now take the case of a tractor. Electric ploughing was much more seriously considered before the days of the tractor. Then it competed with steam ploughing and is in some ways very similar, except that the steam-plough tackle could be moved to the field by its own power and had not to be moved by horses nor did it require any distribution system. With a tractor that can run out with its own plough, one man goes out into the field, starts to work, works by himself all day until he finishes the whole field, and then starts another field. All he has to take with him is a little paraffin and water. Apart from the work at the farm buildings, power is required for hauling and transport at any point over an area of $\frac{1}{2}$ square mile, and on the roads to the station and market, and I think it will be found that the work can be very much better or more easily done by tractors and motor lorries than by electricity. Of course, in the farm buildings, electric lighting is extremely desirable, and it is eminently suitable for driving the small apparatus, e.g. root-cutting and chaff-cutting machines, etc., but, as Mr. Atkinson has already said, a small oil engine will do it quite as well and is as portable. I do all my chaff-cutting, root-cutting and water pumping on the farm with a little $2\frac{1}{2}$-h.p. oil engine. It is so fixed that I can put a belt on the engine and connect it to any one of the machines that I wish to drive. It runs only 5 hours per week and its whole running cost was about £4 for the winter. A water mill grinds my corn, but a little engine of that sort would do that work as well, and is all that the ordinary farmer wants in the way of power in his farm buildings. When it comes to thrashing, there again is the difficulty of moving the thrashing machine about. In Scotland we have fixed thrashing machines to which the corn is brought. In England the custom is to have the stacks in the rickyard or out in the fields, and the thrashing machine is taken to the stack in order to save time and labour. The electrically driven thrashing machine cannot take itself to the stack, and again horses have to be employed and the power transmitted. As to silos, the custom in America is for a silo filler and tractor to travel round the country, visiting silos on different farms. It has only about 4 days' work at each silo and the rest of the year would be lying idle if kept on one farm. Again, in shearing it is often necessary to go a long way from the farm buildings. In spraying, the sprayer must travel through the orchard

or hop garden. It is a moving job for which electricity is eminently unsuited because power cannot easily be conveyed to it. With reference to liquid manure pumping, one is very much tempted, when one sees a great many things being done on the farm by hand labour, to say how much better they could be done by machinery. But it does not pay in most cases to put in machinery, because it is used for such a short time in the year, and even in connection with such a thing as liquid-manure pumping nothing may be saved, as a man stands idle while the motor works. One difficulty in connection with the electrification of crops will be the overhead wires. It will be intolerable to have fields dotted about with poles which will interfere with ploughing and other operations. Between the crops that are grown now and the crops that can be grown there is a far bigger margin available than appears likely to be obtained through electrification. A bad farmer grows perhaps 3 quarters of corn to the acre, and a good farmer will grow 8. There is more than 100 per cent difference between good and bad farming ; it is a question of cultivation, manure and various other things. That is where I think the farmer can get his increased output—in the difference, for instance, between a 400-gallon cow and a 1 000-gallon cow. That is much more important than the question of whether it is milked by hand or by electricity. Money spent on improving his stock and crops may be a much better investment for the farmer than if spent on machinery that may easily prove a nuisance.

Mr. F. Ayton: There are some things in the paper with which I cannot agree. For instance, the author on page 738 rather suggests that the makers of ploughs should adopt a different means of designing their ploughshares. I can assure him that there is a good deal of engineering skill brought to bear in the design of the right surface and curvature of the plough breasts and also in the design of the share which goes at the head of it. There is a good deal of misconception in regard to the subject of speed. It would seem natural to many people that if a plough can be hauled at a higher speed a greater acreage will be ploughed per hour. But when one comes to investigate the matter one finds that it is not justifiable to make that deduction. In 1920 at the National Tractor Show in Kansas, U.S.A., a very interesting paper was read by Mr. Zimmerman before the Society of Automotive Engineers on this question of speed of ploughing, and some figures that he produced support the view that there is a very well-defined limit to the economical and satisfactory speed at which land can be ploughed. Some tests made by the Kansas State Agricultural College were quoted in his paper. Ploughing stubble bottom in light soil and increasing the speed from 2·2 to 3·5 miles per hour, i.e. 59 per cent increased speed, the draft, that is to say the pull required to move the plough through the soil, was increased by 75 per cent. In another case where the increase of speed was 59 per cent in a different soil the increase of draft was 66 per cent. With a breaker bottom, that is to say breaking the land, the speed increased from 3·5 to 5·7 m.p.h. and the draft was increased by 33 per cent. When the matter is examined from the point of view of the amount of power required it will be found that increasing the ploughing speed from 2 to 4 m.p.h. actually increased the power required by 267 per cent. It was found that a 2-furrow plough at 4 m.p.h. covered 1·13 acres per hour, whereas a 3-furrow plough at 2 m.p.h. covered 2·22 acres per hour, i.e. nearly 100 per cent increase, which shows that it is more economical to run the plant at a low speed. These are the deductions which Mr. Zimmerman makes. In theory it would appear to be quite possible to design plough breasts and shares which will plough the land at higher speeds. We have actually built ploughs to plough at over 3 m.p.h., but we have to remember that the British farmer is always anxious to have an unbroken furrow. He is the most particular farmer in the world. Abroad the farmer does not object to a broken furrow, but in England the farmer is always anxious to get a nice, smooth furrow, i.e. a complete line of unbroken earth, and to get that at, say, over 3 m.p.h., a plough breast somewhere about 6 feet long must be used, and our ploughing expert considers that it may be necessary to double that length of breast if speeds of 4 m.p.h. are to be worked to. That is a great objection. Then, again, I would certainly agree with the statements made by Mr. Jenkin as to the undesirability of fitting individual motors to machines which are used for only such a short time in each year. We have fitted integral motors on thrashing machines, for example, where these have been specially ordered. We are always willing to do it but we do not recommend it, because a thrashing machine is used only for a few weeks in the year, and if the motor is built into that machine it lies idle for the greater part of the year and that cannot certainly be good for it. It will probably be found that when the thrashing machine is required the following year the motor is in a dirty state and wants a great deal of attention. Then with regard to electrical ploughing, if we found a demand for electrical ploughing we should certainly develop the plant for it, but the demand does not exist to-day and it is of no use building electrical ploughs until the supply lines and networks have been erected in rural areas so that electricity supply is available on a good many farms. When that does come about I think it will be found that the gear will have to be very much heavier and stronger than the gear used with the steam-ploughing tackle, because so much more power will be available that it may be necessary, I should imagine, to have a slipping clutch on the motor in order to avoid breaking up the ploughs in case obstructions are met.

Mr. J. E. Newman: Before I deal with my own proper subject, which is electro-culture, I should like to say that I have had rather more than twice as long an apprenticeship to farming as one of the previous speakers, as I took to farming in 1906, i.e. 16 years ago. I farm about 500 acres, 400 of which are arable, and I do it almost entirely with tractors. Three tractors and 6 horses are used. The number of hours worked by the tractors in 1921 total 3 500. Of that number 477 were employed on belt work, i.e. thrashing, sawing, grinding, etc. Ploughing took 1 455 hours, and other work—drilling, cultivating, rolling, harrowing and harvesting—totalled 1 118 hours. Making allowances for the different loads and the amount of idle time I find that in round figures this comes to 40 000 h.p.-hours, say 30 000 kWh. On

500 acres this would work out at 60 kWh per acre per annum, or slightly more than the figure given by the author. My land, however, is heavier than that on the author's farm. I quite agree with the previous speaker that the petrol tractor will be, and in the nature of things always must be, a formidable competitor of electricity in almost all the jobs on a farm. It must be remembered that electricity on the farm, apart from belt work, and as far as concerns moving implements, is confined, by reason of the heavy weight of the electric tractor, to cable work, and that for a number of the operations on the farm, some of the utmost importance, a cable cannot be used. Binding, mowing and hauling cannot possibly be done by cable, and therefore some motive power other than the power which is given through a cable must be used for those purposes. Electro-culture is, as has been said, a very big subject, and the amount of literature upon it is appalling. The earliest attempt at electro-culture goes back to 1745, but it was not until the late Professor Lemström at Helsingfors started a series of systematic experiments that the subject was taken up very seriously. An account of Lemström's experiments, which he carried out in Germany, Austria and at Durham University, was published some years ago, and was my first introduction to the subject. I have had the opportunity of carrying out some experiments on Lemström's system which bear out, in general, the correctness of his observations, i.e. that a high-tension continuous discharge over a growing crop did exert a beneficial influence on the plants. But obviously Lemström's system, in which the wires were run about 10 inches over the top of the crop and raised as the crop grew, the poles being 13 yards apart, is absolutely impossible. It is quite obvious that, if the system were to come into practical use, the number of poles must be small and that the agricultural operations must be carried out underneath the wires. Therefore the only thing to do is to raise the wires and to space the poles far apart. In actual practice the interference with farming operations is not so great as would be imagined. In the first large-scale experiments which were carried out near Evesham the poles were placed 70 yards apart in one direction and 100 yards apart in the other. Since then the distance has increased to 8 chains by 5 chains, i.e. one to every 4 acres, so that the poles do not at present interfere very seriously with ordinary agricultural operations. In 1906, after these preliminary experiments, I approached Sir Oliver Lodge and secured his co-operation and that of the late Mr. Raymond Bomford, a very big farmer in Worcestershire, and one of the first to use steam ploughs in England. We started a series of experiments beginning in 1906 and have carried them on, with breaks due to the war and other causes, up to the present time, and they have been claimed to be the first practical trials of electro-culture, at any rate the first trials which could be considered practical from the farming point of view. In the Fifth Kelvin Lecture,* delivered in 1914, Sir Oliver Lodge gave the results that he obtained in this series of experiments. Over the whole series we had an average increase of over 20 per cent, which included one year of drought when no increase at all was obtained. It is interesting to note that in the experiments reported upon by the Electro-Culture Committee the percentage of increase is almost exactly the same. I do not by any means regard that as the maximum possible increase. There is still a great deal to be discovered in regard to electro-culture, and I think it is a matter of regret that the work of the Electro-Culture Committee has been cut short, and that they were not able while they were at work to find out how electricity affects a plant. The author mentions in the paper that he is in agreement with those who think that electricity acts as a stimulant. It may be questioned whether we have always been right as regards the length of time during which we have applied electricity to the plant. It is a matter of common knowledge that stimulants should not be taken too often or too regularly, and it is quite possible that in some of our experiments we have over-stimulated the crop. On one of the experiments which were carried out on my own farm we decided to use for a year much higher currents than we had tried before. It happened to be a year of drought, and for the first fortnight or three weeks we could see a distinct advantage in the electrified crops, but after that it died away, and when it came to harvesting the electrified wheat—it was a case of winter wheat—it was about 3 inches shorter than the un-electrified, and the yield was practically exactly the same. I think there is very little doubt that in that case the plant had been over-stimulated. It is a matter of future experimentation whether in a year of drought, if negative electricity instead of positive electricity be applied, beneficial results will not be obtained. It would have been of great service if the Electro-Culture Committee had devoted more of their time to the investigation of small-scale experiments, i.e. pot-culture work, which can be kept more completely under control and in which results can be obtained more quickly. They would then have obtained more information on points on which we are still quite ignorant. They have arrived at one decision, i.e. that there is a certain critical current which should not be exceeded, but they have not found out what are the hours during which it would pay best to apply the current, or whether a current would give better results if applied intermittently, or whether a negative current would have given better results than a positive current. One point of practical farming interest is that they have made only one trial on leguminous crops, and also that they have confined their experiments almost entirely to cereals. A cereal crop finishes its growth in one year; a crop is practically certain, and it is much easier to measure the yield of wheat or barley or beans than to measure the yield of cabbages, but cereal crops give a low money-return per acre, and it is rather to crops the return from which is of higher value, specialist farming, market gardening and fruit growing that we must look for the immediately profitable field for electro-culture.

* *Journal I.E.E.*, 1914, vol. 52, p. 333.

ADJOURNED DISCUSSION AT THE INSTITUTION, 6 APRIL, 1922.

Mr. H. W. Richardson: I think that Mr. Atkinson might have gone a little further and, having enumerated all the various troubles that might be encountered in electro-farming, have said something to this effect: "Those difficulties and similar difficulties have been overcome in other countries, e.g. Germany, America, Holland and Denmark, and the difficulties that have been overcome in other countries are surely to be overcome by British electrical engineers." It may be said that the conditions are not quite the same in this country, and there is something to be said for this point of view. I believe that hedges are much more common in this country than in other countries. But then, again, it is, I think, well known that electro-farming has made very rapid strides in Hereford. What is actually done in one part of the country is quite capable of being done in another. I feel that the position of electro-farming to-day is much the same as that in which electric cooking and heating was some 10 years ago. Manufacturers have undoubtedly lost some of the benefit that they might have had from cooking and heating if they had tackled the problem whole-heartedly in the early days. We do not want to repeat that mistake and lose business in electro-farming apparatus because we have not prepared early enough for it. There have lately been various conferences on salesmanship, and station engineers, manufacturers, contractors and others have shown how the industry could be better organized. I submit that the results of these conferences could be applied in no way better than to electro-farming, which offers a great scope for advance. First, there is the question of the size of the load that this industry will provide, and I have made one or two rough calculations. The author states that there are 418 000 farms and small holdings in this country. Suppose that we take 60 per cent of these, thus reducing the number to 250 000, each of which may use, say, 2 kW for some 5 hours a day. That will give considerably over 1 000 million kWh per annum. A reference to page 728 will enable that figure to be checked. The author gives the consumption per annum for farm buildings and farm lands as about 54 kW per acre. I think that 26 million acres is about the total of farm land in this country, and by this method we have 1 400 million kWh, which is considerably greater than the figure I have given above. It must be allowed that every farm will not have this density of electrical apparatus on it, but 1 000 million kWh is a fairly sure figure. It is more than the total number of kWh generated and supplied in this country in 1910, so it would be a most valuable addition to our load. For that reason we should not adopt too one-sided a view of the situation. When we, as members of this Institution, are speaking of electro-farming we certainly ought to take into account the advantages as well as the disadvantages. On page 729 transmission is referred to. I suppose that power for the farm will probably be taken in many cases from the transmission lines which are likely to come into being in the near future for main-line railway electrification. I am not sure that we ought to speak as if a three-phase system were absolutely the last word. It has been said quite recently by very competent authorities that probably single-phase systems will have a very fair share of main-line electrification work; so that single-phase as well as three-phase systems should be considered in connection with farm apparatus. On page 730 reference is made to milking. It is said that in New Zealand, for instance, there are something like 9 000 farms employing electric milking machines. I should like to have the author's views as to the fat-content of milk produced by mechanical means. I have always understood from farmers and those interested in the dairy industry that the fat-content could be very much improved by the action of the hands, and it would seem that the mechanical milker is not capable of producing this same action. It must not be overlooked that milking provides a useful load, as it is done early in the morning and in the afternoon. In the summer the load is considerably greater than in the winter. To balance the heavy lighting load in the winter there will be a light milking load, and to compensate for the lesser lighting load in the summer there will be a much heavier milking load. There is one application of electricity which the author does not appear to mention. It is in connection with cows. The variation in the yield power of cows is very considerable. I believe that there are one or two records of cows that have given 3 000 gallons of milk in a season. At any rate, there are several, particularly of the Friesian cattle, that have given yields of 2 000 gallons per annum. There is a great deal of difference between that and, say, the 400, 500 or 600 gallons of milk given by many more ordinary cows. I know, of course, that some of that discrepancy is due to breeding, but much is also due to the conditions under which they are kept, and I am rather surprised that the author does not mention the use of electric fans in cowsheds. Not only is the health of the cattle concerned, but a degree of cleanliness is reached which is not otherwise obtainable. The use of fans would enable our dairy products to be placed on the market in a much better condition. Table 2 deals with the size of motors required on farms, and the author says: "On a farm of 150 to 300 acres a 5-h.p. electric motor is most suitable, as the barn machinery on these farms is slightly larger. On farms of over 300 acres at least 15-h.p. motors are required." I think that when 15-h.p. motors are used, there must also be some smaller motors needed for other processes. I should be glad if the author could state, in connection with his own farm perhaps, or a 300-acre farm, say a mixed farm where there are various farming operations, how many motors would be used and what their approximate sizes would be. I should also like to know the load factor. In Hereford I believe a load factor of something like 20 or 25 per cent has been obtained. On page 732 switchgear is referred to. That is a point to which I think the manufacturer must give attention. All that the farm hand ought to be asked to do is to push a button so as to start up the various motors. On page 734 details of incubators and the electrical rearing of chickens are given, and I feel that the farmer stands to gain much in that direction

because only intensive breeders have previously developed poultry and poultry products to anything like the maximum degree possible. The farmer treats it too much as a side line. But if some very simple apparatus can be devised, requiring practically no attention, it will enable the farmer and also the country to reap the benefit of a much larger poultry production. The matter of electric ploughing is, of course, a great bone of contention. I have not studied the subject to any extent, but I have wondered whether instead of using one 80-h.p. or 100-h.p. motor it would be possible to use two motors of correspondingly smaller output for driving the winding ropes. It would then be possible to use these two units for various other processes, several of which are mentioned in Table 2 as requiring motors of 40 or 50 h.p. This would answer the objection to electric ploughing that one motor is required for so short a space of time in the year. Electro-culture is a very fascinating problem. A little while ago I was studying some figures from Chester, and I found that in some cases Mr. Britton had increased a crop of vegetables by something like 90 per cent. Then, again, not only do the crops increase in size, but they ripen much more rapidly. That is an important point, because it enables more crops to be obtained in the year. There is the question of the cause of the effects produced. The author's deduction is that it is an entirely physical, stimulative effect. To the extent that I have studied this subject, I have rather thought that it was due to some action on the ground. I think that it would be very interesting if, during the period of preparation before the crops were actually sown, some experiments were tried in order to see whether the ground itself is stimulated by the current-carrying wires. The wires could be placed very close to the ground so as to increase the current flowing. Subsequently, when the crop was growing, stimulative current should not be applied. If it were applied it would not be possible to determine, in the event of an increase in productivity, whether the previous ground stimulation were responsible for it, or not. I should like to know the extra capital that would be required on a farm of some 300 or 600 acres for electrical apparatus alone. I think that is important when the amount that the small farmer is able to pay out of his somewhat meagre income is considered, although some farmers of 150 acres are making a great deal more than £112 a year. I do not consider, however, that the electrical industry has studied sufficiently the question of hiring; much might be done by co-operative societies, were hiring facilities available.

Mr. W. R. Cooper: The British farmer possesses a great deal of inertia, and I fear that this will not be easily overcome. In any case I think he will desire to know, and is entitled to know, what monetary results will be gained by the use of electrical methods. This comes down largely to the value of the labour saved, and in this connection it must be remembered that agricultural labour is comparatively cheap. With regard to electro-culture, there is a small omission in the statement that the consumption is $1\frac{1}{2}$ kWh per acre. In judging of the commercial value of electro-culture, it would be of assistance if the author would indicate what might be considered to be the normal value of the crop without electrification. The monetary value of the resultant increase could then be judged more readily. The rotation of crops must here be taken into account. If the financial aspect throughout could be considered by the author, it would add materially to the usefulness of a valuable paper.

Mr. H. A. Carney: I should like to say a few words regarding the importance of improved methods in agriculture in reducing the cost of living. As we have seen during the war, and to some extent since, any increase in the cost of living entails an increase in wages and, in consequence, a still greater increase in the cost of manufactured goods. We are an exporting nation, and therefore low costs are absolutely vital to us. If we are to get low prices and cheap living, we must have efficiency. All our inefficient methods in agriculture must go. I look to an extended application of the use of electricity as the greatest means by which we can make inefficiency in farming disappear. I wish now to turn to the consideration of the size of farm which it pays a farmer to electrify. I have recently been very interested to hear that in Germany electricity has found a more extended use on the small-holdings, and that is exactly the point that I want to make now. In small husbandry—by which I mean such things as poultry-farming, pig-rearing, etc.—it will be found, from the information given in the paper, that very definite commercial results are obtained from the use of electricity. For instance, the case of fowl-house lighting. I think that there is a very much better field for electrical applications in the simple methods such as lighting than in the more complicated and sometimes more doubtful methods of electro-culture. Take, for instance, the bringing of an animal to maturity. The object is to shorten the time as much as possible. The successful pig-keeper never lets his pigs stop growing. The more he can feed them, the quicker he will get them to grow, and at a lower cost. By artificially increasing the hours of light and by properly feeding the animals at suitable times, greater and more rapid growth will be obtained. In the ordinary way it requires 6 months to bring a pig to maturity. If, by increasing the feeding, the pig can be brought to maturity in 4 months, the capacity of the pigsties has been increased by 50 per cent, and as a direct result the cost of production is reduced, as all the standing overhead charges are divided by 3—because 3 periods of 4 months, instead of the usual 2, are obtained. There is a further point. The total amount of food consumed per pig will actually be less to produce the same weight in the case of the pig arriving at maturity in 4 months, for the reason that that part of the food which is consumed in maintaining the body heat of the pig is expended during only 4 months instead of 6. Therefore, it is obvious that the total amount of food must be reduced to that extent, and that, again, is a factor making for economy. The small-holding is essentially a one-man concern. A man farming, let us say, 10 to 20 acres, is not, as a rule, able to employ any labour, but must do everything for himself. I consider that that man stands in much greater need of some cheap, reliable and satisfactory form of power which he can turn on, as it were, by a tap, and which is always ready for him. Electricity is the only power that will fulfil that requirement. Petrol engines or paraffin engines are of no use

to a farmer because, unless he happens to be a mechanic, he will not be able to get satisfactory service from his engine, and, even supposing that he is capable of looking after it, it means that he will have to spend time in pure engineering which would be better spent in farming, and farming is his main business. Basing my remarks on the figures given by the author on page 728, I should like to refer to the question of the annual consumption on various farms. Let us take, first of all, the largest farm, i.e. the 600-acre farm, which has a maximum demand of 15 h.p. If that farm were properly electrified, the annual consumption would apparently be 26 000 kWh per annum per square mile. I think that no supply authority would refuse to supply that. But if we suppose that the square mile has 64 small farms on it instead of one, the area of each being approximately 10 acres, the consumption per square mile will be increased, because there will be 64 farmhouses and 64 sets of farm buildings. The consumption in that case would be at least 30 000 kWh per square mile and, as it would be sold to small consumers, a higher rate per kWh might be charged. I think that the conclusion to be drawn is that, from the point of view of the farmer and from that of the supply authority, the smaller the farm the more profitable will it be to supply it on proper lines by electricity and the more profitable will it be for the farmer to use the supply. The amount of overhead work necessary to give a supply depends, of course, on the position of the farm relative to the pole line. In the case of the small farm, a very considerable amount of pole-line construction might be necessary in order to give a supply, particularly in the early stages. I understand that in New Zealand the supply authority considers that it is perfectly good business to run pole lines out merely to supply the milking-machine load. Their experience is that the demand increases as the farmer gets accustomed to the use of electricity. I believe that the use of electrically driven milking machines is increasing there at the rate of 16 per cent per annum, and that already 25 per cent of the total milking machines in the country are driven electrically. One way in which the difficulty of extensive overhead construction by power supply authorities can be overcome is by co-operation between neighbouring small-holdings, as the small-holders can form themselves into a group and take a common supply from the nearest overhead lines. They could take a bulk supply, and the current could then be distributed on lines erected by the small-holders themselves. Sufficient technical assistance could be given by the supply authority. Practically the only apparatus to be bought would be the insulators, the conductors, and the insulator pins. Therefore, the small-holders would be in a position to construct their own distribution lines at the minimum cost. The supply authority, on the other hand, would have the advantage of supplying to large consumers.

Mr. C. G. Hyde: As in nearly all cases of conversion to electric drive, when electric power is used in farming it is not only the direct cost of power and upkeep which shows improvement. I should have been glad if the author had brought out this point. He has carried out his experiments on a commercial scale and has kept very comprehensive accounts by machine. Presumably some accounts were kept on the farm before it was electrified, in which case it would be instructive to compare the two sets of figures. Though electric ploughing may be desirable from the load point of view, a satisfactory solution of this problem has by no means been reached. The system put forward by the author entails the complication of two drums, each of which has, I imagine, to hold about three times as much cable as each drum on the double-machine ploughing system. It would be interesting to see what means are suggested for conveying the power to the fields. Some kind of temporary line is required, on the score of cost. For supplying power to farms the high-tension overhead line is of course the best, though unfortunately practically non-existent in this country. The author refers to the use of a 50-kVA transformer, but I have seen 5-kVA and smaller transformers in use when permanently connected to the supply. Only lighting and small motor circuits are connected to these. Larger motors are mounted in vans together with suitable transformers, and these are coupled to the high-tension line as required, through overhead pole contacts. When power stations have to be built for farm work it would be better for small-holders to combine on grounds of economy, using three-phase current at 1 500 volts or higher for their supply. The isolated plant may be a sound proposition if there is any water power available, even if only a small amount, in which case heavy loads occurring during thrashing, etc., could be dealt with by a suction-gas or oil-engine set. There should be no trouble with motors, as the majority of good makes are now insulated for any atmospherical conditions. The squirrel-cage type should be used, if possible, as brush-gear and starters are out of place on a farm. It should be possible to switch the motors straight on to the line, as voltage-drop need not be considered. In conclusion, I wish to point out that investigations must be made to show the advantages to be expected in any direction, so that the electrical engineer, whose duty it will be to convince the farmer that he can be helped in his job, may be as fully informed as possible.

Mr. C. J. Hopkins: The paper may be conveniently divided into two main parts: (1) the application of electricity to machinery and lighting, and (2) electrical treatment of farm products, e.g. crops, silage, milk, etc. With regard to electric lighting, I am quite sure that if a farmer could be induced to install it, he would always want it. The great difficulty in England is that public electricity supplies are not yet available for the farms; if they did exist, many more farmers would use electricity, not only for lighting but also for power. With reference to power for fixed machinery, the author recommends individual motors for various machines That is, no doubt, a good idea, but it certainly involves more capital, and, considering that the load factor of such motors is very small, I do not know that it would be good to advocate that system at first. I think that line shafting (on ball bearings) driven by one motor with belt connections to the separate machines would be preferable. With regard to ploughing, all those connected with farming know that it fulfils two purposes, one being the breaking up of the soil and the other the killing of the weeds. If the corn is shocked in rows it is

possible—and a good many farmers have taken advantage of this fact recently—to plough between the shocks with tractors, and so kill the weeds while the sun is hot (horse ploughing would be too slow to accomplish any appreciable amount of work in the limited time remaining after the corn is cut). By this means much labour is saved that might otherwise be required to clean the ground, and the land is ready for further production at an earlier date and will produce more per acre. The author suggests the drying of the sheaves of corn, when harvesting, by means of electrical apparatus. If that could be done, thus permitting the clearing of the fields immediately after cutting, the rope plough, electric or otherwise, could be used as there would be no shocks in the way. The author's desire for greater ploughing speeds is to be highly commended, as much time and expense is absorbed in this occupation, while the land often lies idle longer than necessary, waiting to be ploughed. The fact that some farmers still insist on unbroken furrows, which can be obtained only by slow ploughing, as pointed out by Mr. Ayton, seems inconsistent, as the first thing to be done after ploughing is to break up the furrows by the further use of farm implements. With reference to the author's suggestion that smaller thrashers might be used, if electric ploughing is carried out on the farm, that will determine the maximum demand, and nothing else need be considered; otherwise thrashing may produce an objectionable peak load. The author refers to certain implement engineers catering for a restricted demand for electric power, by dividing the thrashing machine into two parts, one for thrashing and cleaning slightly, and the other for cleaning at a later period. I believe that that has been the usual practice. Apart from that, the cleaning takes a very small amount of power, i.e. ½ h.p., according to Table 2. Another point is that it is better not to thrash too slowly, in order that a rick when opened for thrashing may be finished the same day, and not left exposed to the possibility of bad weather conditions. I should not condemn curing hay by electrically driven machinery, but there are two or three points that need to be carefully considered. First, suppose that grass is cut when it is wet and that air is passed through it for 30 hours or so after it has been stacked wet. I am of the opinion that with any fair-sized rick, say 25 to 35 tons, mould will form towards the outside, as it will not be dried sufficiently. Then there is the chance of the machine stopping, in which case the rick might easily overheat and catch fire very quickly. Again, if the curing takes 30 hours, a day and a night shift are necessary, and this is a disadvantage unless a public supply of electricity is at hand. As to harvesting, I do not know whether there would be any advantage in putting a motor on a harvesting machine for driving the machinery, as I have never found any disadvantage in going round corners with reduced knife speed. On the other hand, if a self-binder be driven by a motor, when the oscillating knife runs into mole-casts or stones the machinery is more likely to be broken than when driven by the carrying (or bull) wheel which otherwise becomes blocked, skids and automatically stops the machine, with little or no damage to the knife. The author says that milking machines, if operated under the supervision of the farmer or his son, have been a great success. I admit that they should be, but I do not think that they have been in this country, because the farmer does not know how to investigate any trouble that arises. As to repairs, the average farmer objects to complicated machinery simply because repairs are so expensive. During the past year or two electric welding has been developed, so that it is now possible to repair quite quickly practically any machine part made of iron or steel at a cost greatly below that of new parts. Unfortunately, farmers do not realize this, and confuse acetylene welding with electric welding, being ignorant of the fact that there is just as much difference between the two methods of welding as between gas lighting and electric lighting. It must be borne in mind that the welding itself must be undertaken by a qualified man. If the farmer tries to do it himself the percentage of successful repairs will probably not be very great. A number of illustrations of electrically welded parts of agricultural implements (some recovered from the scrap-heap) are given in the technical Press.* The author's remarks with regard to the design of large incubators are very valuable and should advance this business considerably. He states that chickens raised by electrically operated incubators are healthier than those raised in the natural way. Such a statement would, however, be hard to prove, and could not advisedly be used as an argument with a farmer, because he would certainly object to it. The author refers to the use of wireless telephony. A telephone ought to be considered a necessity at a farm house, as it is frequently an isolated place. From the standpoint of weather reports, the farmer decides about 7 or 8 a.m. what he is going to do for the day, so that 5 or 6 weather reports during the day will not be of great assistance to him.

Mr. E. K. Scott: In certain selected cases of large farms it may in future be found possible to make nitrate fertilizers on the premises. For instance, some estates enclose a waterfall and there are some colliery and mining companies who own large farms for the sake of the minerals underneath. In such cases electric power can be produced cheaply and in sufficient amount to make fertilizer by the arc process. In this process nitrate of lime is made by simply blowing air through an electric arc and combining the resultant gas with lime to make calcium nitrate, the only raw materials being air, water and limestone. Clearly, if nitrate fertilizers were made here, a good deal of money would be expended at home which now goes overseas. Before and during the war the Chilian nitrate group endeavoured by propaganda to discourage the starting of any method of making nitrates from the air, but the Germans who had to depend entirely on the air for explosives and fertilizers proved conclusively that it could be done. Their large plants can now make artificial nitrate fertilizers more cheaply than natural nitrates can be obtained from Chile. In addition to criticism and opposition from those who did not want any form of air nitrate process started, the particular one I have in mind, namely the arc process, has been criticized by those who were interested in other processes, e.g. by those interested in the method of making cyanamid.

* See, for instance, *Agricultural Engineering*.

This method is, however, very complicated and the arc process is much better because of its simplicity and directness. It is now recognized that nitrate of lime made by the arc process in Norway and elsewhere is an excellent fertilizer, and is in many cases preferable to sodium nitrate and ammonia and cyanamid fertilizers. It is true that in Norway the nitrate of lime is made on a very large scale and by continuous operations, but that is because it suits Norway to work in that way. Nitrate of lime can be made quite as well on a small scale and with intermittent power, and relatively small plants have been worked in Italy, France and the United States for some years. It might be thought that the work would be too skilled for a farmer, but it is a peculiarity of the arc process that very little skill is required. A small plant was run during the war by two women who had not had any previous engineering or chemical experience. If women can run such a plant involving experimental work then surely the hypothetical farmer on a large scale with electric power at his disposal can make his own fertilizer with standardized plant on which there would be no experiments. I believe that some day we shall see artificial fertilizers made by those who use them extensively. Successful farming on a large scale is becoming more and more an engineering and chemical proposition, and the engineering and chemistry involved in making nitrate fertilizer by the arc process from the air is not difficult.

Mr. C. T. Allan (*communicated*): The paper gives the latest European practice and much very useful new information. I have noticed that farmers are more conservative than their wives and that if a labour-saving flat-iron is introduced other appliances follow. A farm illuminated with paraffin lamps with the attendant trouble of cleaning, cost and maintenance, will adopt electric light as soon as it is available. I know that electric light in stables, cow-houses, etc., is welcomed and I know also, from experience over several years, that electrically lit hen-houses increase the output of eggs. In my experiments I have used a time switch to operate the electric lights so that the illumination in winter is for about 15 hours a day. The light is operated only once a day, viz. from the early morning to daylight, which means that in some parts of the winter the light is switched on at 3 a.m. As regards tariffs, one method is to tell the farmers that they will have the same tariff as the consumers in the villages if several of them will jointly arrange to take supply and bear the moderate capital cost of running the low-tension mains. I think that slot meters arranged for a slightly higher price per unit are excellent in helping to pay off hire-purchased plant. The consumer does not object to the odd shillings put in the slot meter so much as he does to the periodical invoices for instalments. For saving trouble to farmers' wives, the flat-iron, vacuum cleaner, washing machine and even ironing machine, are extremely helpful. As a commencement, with low first costs, motors to drive milking machines, chaff cutters, root pulpers, cake breakers, wood cutters and saws, water and sewage pumps, appeal to farmers. Afterwards they can use the more expensive appliances. Supply engineers should note that they will have more trouble from farmers than from collieries or works, should a feeder be made dead during milking time, because the cows cannot wait and the farmers cannot find sufficient hand-milkers. I agree with the author that motors should be damp-proof and dust-proof and fitted with ball bearings, and I recommend totally enclosed motors. There is then no trouble due to chaff, dust, etc., fouling the windings. It is interesting to note that the average size of small motors is 5 h.p., also that the speed of the machines to be driven varies from 1 800 to 30 r.p.m., and I suggest that motors of this size fitted to a portable trestle, as recommended by the author, but combined with a simple variable reduction gear and flexible shaft with universal sockets for the latter on each machine, would remedy belt and other troubles. I believe that it is possible to develop this reduction gear. It is not often that more than 2 motors are running at the same time on a small farm. It may not be generally known that two Manchester men—William Chorlton, farmer, and E. O. Walker, electrical engineer—put together and operated a plant for ploughing by electricity the farmer's 240-acre farm at Cotgrave near Nottingham in 1910. A 25-h.p. suction gas engine drove a 20-kW, 500-volt d.c. generator. Two carriages on the double-winder system mounted with haulage gears and motors, hauled a 3-furrow balance plough through soil of such a sticky and tenacious nature that it formerly required 3 and frequently 4 shire horses to draw a single-furrow plough. The same machine operated a cultivator and drove thrashing and other farm machinery. The overhead wires and poles were light and portable, offering no difficulty in changing from field to field. Mr. Chorlton informed me that the whole plant was run without any expert and was in charge of the farm foreman. This equipment was described in the *Manchester Guardian* of 24 February, 1911, and in the *Electrical Review* of 9 February, 1916. The owner sold the farm in 1917 and retired. The haulages went to Scotland and afterwards to Suffolk and are still working, but are now hauling timber. This was possibly one of the first electric ploughing plants to be commercially used. Having seen oil-engine tractors, oil-engine haulages and steam haulages doing ploughing and mole draining, I believe, with the author, that there is a considerable future for electric ploughing. I also believe that the local farmers' society, or even the supply undertakings, will own one or more of these machines and contract for the work. In experiments which I have carried out on electro-culture, I found that a $2\frac{1}{2}$-acre field planted with potatoes yielded a 17 per cent increase the first year and a 10 per cent increase the second year on the electrically treated part, over the untreated portion. The experiments were not continued, because the field was taken over by the owner, but they will be continued when another field can be obtained. I also have noticed the effect of high-tension discharge on insects; it seems to make their wings and legs act like electroscopes. This might be worth further investigation, especially in hop fields, where it may partly or completely obviate the necessity of spraying. So far as I am aware, no large-scale experiments have been made on the effect of discharge over fruit trees or young forest-tree plantations, etc. Results of tests would be interesting and may prove that the growth is accelerated. It should be borne in mind, however, that

the treatment should not be applied during the time the trees are in flower, otherwise bees and other fertilizing insects may be prevented from carrying out their work. High-tension discharge over live-stock housed in buildings with specially tinted windows may also prove another interesting field for experiment. The author's suggestion of a drying room for fruit, vegetables, etc., is excellent. If situated near the farm house, the housewife could use it for drying clothes, which are often so difficult to deal with in winter weather. With a fan in the drying room, perhaps the hot air could be used to warm the house or even a forcing house for early produce. The artificial drying of hay and the electrical treatment of silage are two of the latest and most interesting applications which when better known will undoubtedly make a special appeal to the farmer. As in South Wales, no doubt other supply engineers find that their transmission lines between one industrial centre and another traverse farm land as well as moor-land, and, because these lines are already earning sufficient revenue to cover more than capital charges, the tariffs to farmers could be so low as to make it impossible for any other sort of power to compete with electricity. Farmers naturally strongly object to pole lines crossing their property, on account of inconvenience to their operations, but see the question in a different light when it is explained to them that the lines are also available for their use. The scheme is to get a group of them interested so as to locate the joint substation in their electrical centre of gravity, in which case the cost will be cheaper to them individually. The "Auto-Countancy" system machine devised by the author, if expensive for the individual farmer, might be purchased by the local farmers' society, each farmer using it when he has need of it, or purchasing one when he can afford it. I believe that this machine, when better known, will save many a farmer from the worry of wondering whether he is solvent or not, in addition to his other troubles.

Mr. J. Eck (*communicated*): The author's list of uses of electricity on the farm is most interesting and instructive, and shows a great range of possibilities that should lead to many practical results both for the farmer and the electrical engineer. I do not like the use of ball-bearings on electric motors, even for shafting, in farm work. Ball bearings are suitable where they can be carefully studied and well looked after, but on a farm where there is evidently difficulty in obtaining attention for ordinary belts, ball bearings would be a failure. On a farm, motors must be simple to start, and free from repairs and from harm or damage by falling matter, and therefore a well-enclosed but ventilated type of machine is the only one likely to be suitable. Such a motor must be provided with self-oiling bearings with ample oil storage. To secure easy starting the motors should be either fitted with a device to relieve the belt tension so that the load can be freed from load when starting up, or, alternatively, they should have centrifugal friction clutches to take up the load when the motor has gained speed, because it is clear that in almost all cases the squirrel-cage motor, in spite of its low starting torque, is the best for the purpose. Where slip-ring motors are required the motors should be provided with internal starting resistances and a simple lever device that will eliminate these by a straightforward movement. The price of current will have a considerable influence on the adoption of electric power driving, and it is therefore desirable that the load factor should be increased. This could be effected by the addition of house and farm lighting, some chemical process, such as nitrate production, or the use of co-operatively owned special motors and appliances, as well as the inception of local industries and the extended use of electric cooking apparatus. The size of farms depends entirely upon the class of culture, and who does the work. On the Continent quite small farms of 10 acres and upwards use electrical motors with remarkable success, due probably to the fact that these are one-family undertakings,where the workers' time can and will always be fully occupied, and also because such a small farm-owner is usually highly skilled and readily adapts himself to the advantages of electric driving. The next larger class of farms is probably not so well suited for electrical driving, unless they are worked on the intensive plan, but such obviously small figures of turnover as £5 per acre which Mr. Atkinson indicates for farming are undesirable, and such farmers should give place to people who will introduce more successful methods of farming with larger turnover. A really large farm possesses opportunities of having a proper managing farmer and of distributing the labour in such a way as to get as good an utilization of electric power as on the small one-family farm. With respect to financing the cost of the electric motors and of the appliances, this undoubtedly must be done by the supply undertaking, which can purchase the machinery at the lowest possible price and then sell it on terms that will bring interest on their capital, as well as a replacement of the total capital during two or three years, at about which time this same capital would be needed for increasing their area of supply. This system is adopted abroad and has proved successful. With regard to the cost of connection, the supply must undoubtedly be given through overhead wires; underground conductors would prove far too expensive. Electric ploughing is suitable for large farms of 1 000 acres and upwards, and by co-operative working presents advantages in cost against the use of paraffin-driven tractors, due to the simplicity of the motors, their small upkeep costs and their moderate first cost. The transformers used at distribution points can be specially constructed so that the first cost need not be great and so that they can stand heavy overloads with good efficiency for long periods, in fact, a special design of "Agricultural" transformer.

Mr. W. B. Esson (*communicated*): I do not like the primary title "Electro-Farming" as this would ordinarily convey the same meaning as is conveyed by the term "Electro-Culture," used later in the appendix, but the sub-title is suitable. At the same time, "The Applications of Engineering to Agriculture" would, in my opinion, be a much better title, because the author approaches the subject as a mechanical engineer and he introduces electricity only because every up-to-date engineer knows that if power is to be distributed in small quantities in a straggling area, the only vehicle to do this efficiently is electricity. The author has made it his business to apply, in an intensive way, his engineering ability to farming, not, as he says, for a mere hobby, but with a

view to making it pay. I have had an opportunity of seeing what he has done on his farm. He is, of course, fortunate in possessing not only the farming and engineering knowledge, but also the requisite capital to enable him to put down whatever equipment he wishes, and to carry out just what experiments he pleases, but he no doubt knows that in most cases, when any proposition for substituting power for hand labour is put forward, it is the difficulty of obtaining the requisite capital that is the crux of the matter. It is useless to tell a farmer that if he expends a couple of thousand pounds he could clear another £300 or £400 a year, if he has not got the money or if his bank is too sceptical to advance it. In that case, and until some kind of organization is at work which will come to the aid of farmers in this position, the great majority of them will just have to go on in the old way. Provided that the savings to be effected can be placed beyond doubt, it should be quite possible, however, to bring into being some organization of the kind. But even if a farmer wanted to be as up-to-date as possible and had the money ready to spend, I am not sure that the paper gives any guidance as to whether he should spend the money or not. The summary of the uses to which electricity can be put, the data as to the design and size of motors, the information as regards hours of working, and the excellent descriptions in the appendix of the various electrical applications are all very valuable, but it is the money point of view that interests the farmer and also the engineer, because his orders will come from the farmer, and I am disappointed to find that no particulars are given in the paper as to capital outlay or savings effected. The author states that for farms under 150 acres careful thought must be given to ensure that an adequate return is obtained for the capital expended, from which it may be gathered that, with careful thought, on farms over 150 acres an adequate return can be obtained, but he stops there. Again, we are told what the maximum demand and units consumed are estimated to be on a farm of 600 acres, but though this is the size of the author's own farm there is no information regarding the capital he has put in and the direct savings he has effected, which are the very things we want to know. There is, of course, no definite relation between the maximum demand and the horse-power installed; this would be different for each farm and would depend upon the proportion of portable motors. By telling us that that maximum demand on a 600-acre farm is 15 h.p. it seems then that the author gives no clue to the expenditure, though the latter is the most important matter. If we are to convince farmers we should have all the figures. They are a most conservative race, and only hard facts and unassailable figures as to savings will induce them to make a move. It will be a long time before we see a distribution network put up for agricultural purposes in this country, so that the oil engine is not likely to be superseded for some time. The 600-acre farm mentioned in the paper, with a maximum demand of 15 h.p. and 6 000 kWh used on the farm buildings, has a load factor of only a little over 6 per cent, which is very poor from the power-house point of view. The author says that the load factor for this farm, or rather for a group of similar farms, when completely equipped is satisfactory, but he does not say what it is. Would he accept 15 per cent as a reasonable figure, having regard to all the conditions of working? If just for argument's sake we take that figure, then for 6 000 kWh for farm buildings and 26 400 kWh for farm-land (or 32 400 kWh in all per annum) we should have a maximum demand of 25 kW or so. Since each 600-acre farm may be regarded as about a mile square we have as a result that the demand for agricultural purposes would be at the most only 25 kW per square mile, a figure which no power house would consider. Farms within a reasonable distance of a power-line route may get a supply, but a general network to capture such a small demand as I have mentioned is, I fear, out of the question. But in any case there is the oil engine to drive a generator, which would probably enable electricity to be produced as cheaply as it could be bought from a company. Intimately influencing this question are the conditions on which land is held. The author is the owner of his farm and he is free to do what he likes, but a leaseholder is in a vastly different position. It will not pay such a man to invest capital unless the term of his lease is such that he will be able to get, while it lasts, a good return for his outlay, and to build up while it lasts a sinking fund sufficient to redeem his capital at the end of the term. If the plant he laid down came under tenant's fixtures he would probably get little advantage from that, since it is quite possible that it would not be worth moving when he himself had to move. Virtually our land tenure provides that, of the total produce, the farmer is allowed such amount as will pay his outgoings, the interest on his capital, his trade risks and some remuneration for management, while the remainder goes to the landlord in the form of rent. This is all very well for the peasant farmer of the past, but it is not good enough to attract men with brains and scientific training. The latter quite rightly want the full reward of their energy and enterprise, and so I fear that the author has unwittingly raised some very knotty problems. I am glad to hear that he is going to turn his attention to electro-culture, and I shall look forward with interest to the results obtained. Though there is no doubt a considerable increase in the produce when crops are electrically treated, very few definite facts are known, and I hope that the author will be able to clear up a good many of the debatable points. This paper and other papers he is writing should certainly create some stir in farming circles and should give a distinct impetus to the application of electricity to agricultural work.

Mr. W. S. Flight (*communicated*): The author and several speakers have referred to the electrification of crops by means of overhead wires. I understand that in Germany experiments have been carried out by placing wires in the soil on each side of a field and passing current from an induction coil through the ground. The treatment given is intermittent, being applied for 4 to 6 hours every 2 or 3 days. One set can therefore be used for several fields; the cost of the wires is much lower than with the overhead system; there is no danger to men working in the field; and, as there are no poles, farming operations are not interfered with. It has been claimed that

this root system of crop stimulation has yielded higher increases than the overhead system and it has in addition the following advantages. By giving the electrical treatment in conjunction with certain chemical treatment, weeds may be destroyed, wireworm and other soil pests may be killed, and sour land can be made sweet and fruitful. The author attributes the stimulation produced by the overhead treatment to the formation of nitrogen compounds, ozone, etc. The stimulation by the soil treatment is supposed to be due to increased capillary action of the roots. Due to this increased root action plants require only 10 per cent of the fertilizing material which would otherwise be necessary. A modification of this system has been successfully employed for treating fruit trees affected with fungoid diseases. It has also been claimed that by subjecting seeds to a high-frequency discharge their germinating power can be increased. It would be of considerable interest if the author could say whether these truly wonderful claims have been substantiated on a large scale, and if any of these systems are extensively employed either in this country or abroad.

Mr. B. J. Owen (*communicated*): The discussion at the first meeting showed that it is not merely the adaptation of electrical machinery to the farm, but the limits within which farm economics will allow electrical machinery to be applied, that must be considered. At the outset I should like to say that the Ministry of Agriculture has a branch dealing, *inter alia*, with the development of agricultural machinery, and one of the subjects it intends to investigate is the application of electricity to the farm. The Ministry has also appointed a special Committee to investigate the subject of electro-culture. A commencement has been made in Herefordshire to apply electricity for farming purposes. In this case electricity is being used on a fairly large scale, and data which will indicate the comparative costs between the employment of one motive power and another, in this case electrical power and internal-combustion power, are being collected. I have had the opportunity of studying electrical farming abroad, and it must be admitted that considerable progress has been made there in utilizing electricity for almost every farm operation at a surprisingly low cost, in fact a cost which compares favourably with every other form of motive power. This is especially evident in Northern Europe where an unlimited water supply is available. Conditions in England may not admit of the same extensive application, but no doubt steps could be taken to establish a system on similar lines, and perhaps the recommendations of the Water Resources Committee will assist considerably in this direction. One of the principal reasons that development in England has been so slow is that the attitude of farmers has not been encouraging to the adoption of motive power. This attitude has, however, been considerably modified since the introduction by the Government of large quantities of motor tractors during the war. Farming at the present time may be regarded as being in a very low financial condition, but this condition can be improved by the adoption of machinery specifically produced to meet farming conditions. As the author has indicated, engineers unfortunately do not seem to have devoted much attention to farm problems, regarding them in the same manner as ordinary engineering industrial problems, whereas they are quite distinct. Owing to this cause and a general lack of data, it is difficult to advise farmers as to the form of power which should be employed for any stated conditions. The question is obviously complicated by many economic factors which are indicated in the paper, such as the size of the farm, the type of farming, and the capital outlay. The farm cannot be regarded on the lines of an engineering workshop where most of the factors are measurable; the farm is at the mercy of the elements which will cause anticipated profits to disappear as the result of a poor season. However, it is the hope of the Ministry, within reasonable limits, to obtain data which will enable advice to be given to farmers, indicating the possibility of using electricity on the farm. I shall now refer to the subject of agricultural implement design. As the Ministry of Agriculture has issued a White Paper Report of the Departmental Committee on Agricultural Machinery (Cmd. 506), which deals very fully with the subject of agricultural machinery development, I do not propose to deal with this point at too great a length. I wish, however, to associate myself with the views on ploughs held by the author, which were criticized by one speaker, who objected to the author's statement that "the scientific principles of the design of even such features as plough shares do not seem to have been as carefully investigated or mathematically analysed as they should have been. . . ." The investigations of the Research Branch of the Ministry confirm this view. The paper read by Mr. Zimmerman before the American Society of Engineers, referred to by Mr. Ayton, is quite familiar to the Ministry and it is felt that Mr. Zimmerman did not wish to imply that the speed of the plough cannot be increased, but that the lack of scientific data makes it impossible to know exactly where to commence. This view is also taken by M. Ringelman of the Station d'Essais, Ecole de Grignon, Paris, and other scientific workers. There is a wide field for research work in connection with all cultivating implements. The plough has departed very little from its original design; the same principle is maintained as when it was first introduced. No data are, however, available on the relations existing between the type of mouldboard and the type of soil, the velocity and the curvature, etc. The majority of the work has been highly empirical and this is reflected in the number of types of mouldboards instanced by the author. The Ringelman formula for the tractive effort needed to plough, quoted by the author, is open to question, for the relation represented by the symbol for depth of furrow cannot be regarded as a constant, as it is difficult to say whether the same load per square foot cross-section would be imposed at varying depths. From evidence already collected it is evident that the character of a stratum of soil is not necessarily uniform. To demonstrate further the difficulties in connection with the design of cultivating implements, the following view, supported by Sir John Russell, of Rothamsted, is quoted:

"Until research has been carried out it is impossible to say whether ploughing is actually an essential operation. There is little precise knowledge of the physical factors involved in the production of tilth or, indeed, what is the best kind of tilth, as little is known of the precise mechanical effect of the soil on the implements of tillage. In the present state of knowledge it is impossible to state from scientific evidence which is the best type of plough for use in any given circumstances nor, indeed, can an answer be given with any assurance to the question whether ploughing is an essential operation, and the same ignorance must be confessed in the case of other cultivating implements, so that to-day a designer would base his design largely on empirical knowledge, not knowing exactly what is required of a particular machine or implement." The author has defined the application of electricity in a very comprehensive table but he no doubt regards this table as the ideal application. It is dubious, however, whether farmers will employ electricity on such an extensive scale unless, of course, all the circumstances are very favourable. There are several important points entering into the question, but they are fundamentally economic. The application of electricity in relation to farm economics may be divided into two problems: (1) Current supplied by a supply undertaking, and (2) current generated on the farm. The first involves the question of the extent to which electricity can be used in this country for ploughing and other heavy operations. This depends upon the creation of central power stations and the construction of a network of transmission lines. The supply of electricity to farmers at a cost comparable with that of existing sources of supply would undoubtedly be of service as, apart from the advantages enumerated in the paper, it would lead to development of village industries and make the life of agricultural workers in winter months more comfortable. I feel, however, that the agricultural demand for electricity would be fluctuating and perhaps be comparatively slight, and development in this direction will depend largely on other industries. I shall deal later with this important point. The second problem can, of course, be subdivided for different power driving units, but there is the question of the utilization of small powers, e.g. the kinetic energy of wind and water. There is a large amount of water power now allowed to run to waste in hillside streams, many of which would be capable of commercial development and from which villages and farmsteads could obtain electric power. Denmark has successfully developed windmills as generating units and almost every farm possesses a windmill for this purpose. I should like to refer to certain statements made by Mr. Atkinson who, I think, suggested that it is almost an economic impossibility to apply electricity on the farm. The basis of his calculation was a 150-acre farm and on pre-war statistics. He said that the total expenditure was £4 19s. 3d. per acre, and that the total yield was £5 14s. 3d. per acre, i.e. a net profit of 15s. per acre, or £112 per year on a 150-acre farm. I do not know the source of these figures, but according to statistics in the possession of the Ministry of Agriculture they are a serious under-estimation. However, I shall assume that they are correct. Before dealing with the method employed by the speaker, it may be well to determine what is involved. The problem may be stated symbolically as follows: Let a series of operations cost £X, and let a return for the operation be £Y. Introduce the cost of electricity as £X', and let the return be £Y'. If $X' = Y$, then $Y - X$ is less than $X' - Y'$. Now what are the factors determining X' and Y'? According to the speaker the value of X' must be so great that $Y' - X$ is less than $Y - X$. If that is so, enterprise becomes impossible. To proceed further, is it fair to assume an arithmetical average as an economic basis? An arithmetical average has no meaning in real life for it neglects the first principle of statistics which deals with economic issues in a series of groups and dependent groups. In farming, for instance, market gardening, small-holdings, pure arable farming and mixed farming are wide variables, all having different economic relations. Large mixed farming may represent the predominant type of farming in a county and this must be regarded as a group or an economic unit. The problem must therefore be regarded in terms of economic groups representing a series of norms which can only be the true average. It can easily be proved by the arithmetical average that motor tractors on the farm are absurd although there are at least 20 000 in use and the annual demand is still considerable. It is a case of *reductio ad absurdum*. A norm in one county may be different from a norm in another county for various farming reasons, but this norm will definitely indicate the optimum and minimum limits within which the development of electricity is possible. Small-holdings may be predominant in a county, but on the other hand there may be large farms of over 1 500 acres. The optimum figure would be the latter, so that the economic unit for the larger farms would be totally different from that for the smaller farms. It is also absurd to suppose that agriculture is the only industry. Farming must not be regarded *in vacuo* for, if so, all problems would become insoluble. A case in point may be cited. The Ministry have a 1 500-acre farm in Norfolk, surrounded by farms of similar areas with some small-holdings and market gardens. There are villages in this area, some of which have small industries. The agricultural demand for electricity would be subsidiary to the village industry demand, but the economic unit for electricity must be regarded as farm plus industry. An economic problem is thus regarded as a group problem and the ultimate issue would be regarded from two standpoints, viz. that of the farmers and that of the nation. The former resolves itself into the question: "How can the 15s. be increased to, say, 18s. 6d.?" The latter may be stated thus: "How can the cost of production be reduced and thus incidentally make the 15s. worth more?" No simple answer can be given but it resolves itself into what is the minimum and what is the optimum scale at which electricity can be applied, either in relation to a supply undertaking or to a farm generating system, and it can be decided only by experiment. It is possible, of course, to regard the success of Continental

systems for agriculture as being proof of the success of such experiments, and perhaps a further proof is the fact that the author has commercially applied electricity without any apparent loss to himself.

Major T. Vincent Smith (*communicated*): The author is quite right in questioning the advisability of sterilizing milk. The truth is that it is not the milk which should be sterilized but every vessel and cooler with which it comes in contact. Dr. Stenhouse Williams of the National Institute for Research in Dairying at Reading, in whose work I am deeply interested, is such a leading authority on this important subject that I make no apology for quoting his views: (1) If milk has to be sterilized, it shows that bacteria have been introduced by the use of unclean methods and, as the effect of sterilization is to deteriorate the quality and food value of the milk, it follows that the greatest care should be taken to secure the cleanliness of milkers, cows, and their surroundings. (2) However clean the milk is, when produced, it is most rapidly contaminated upon being brought into contact with coolers and vessels which have not been sterilized, and at once its keeping quality rapidly diminishes. (3) Half methods are bad because they are deceptive, and sterilization to be effective demands that the temperature of 212° F. must be maintained for a definite time. Using steam under pressure, 3 minutes is sufficient, but for an ordinary current of steam 8 minutes is necessary, and in all cases the object to be sterilized must be covered up in order to maintain the necessary temperature.

Mr. W. A. Turnbull (*communicated*): The author does not mention a means whereby an isolated farm can notify the supply undertaking that his supply has failed. I suggest that the neutral should be brought back to the generating station, when, by means of sympathetic pendulums, the farmer could call for attention. A trouble in a fertile vale is the blockage of the streams with weeds and rushes. Would the electrolytic production of chlorine from salt kill the weeds and not the cattle? I am of opinion that the most practical form of electric ploughing is by means of trolley wires supported on light tripods capable of being lifted bodily from the ground by the rigid plough trolley-arm, which would keep moving the supports as the land was ploughed. Can the author say if this method has been tried? If a town tenant were to wire his house for electric light, the landlord might raise his rent. If this applies to a farmer, does the author think that the Rent Restriction Act would meet the case, to the advantage of development?

Mr. W. Wilson (*communicated*): The subject of the paper is of special interest to me, as I received my first consulting fee in 1906 in connection with the driving of a milking machine serving a herd of 150 cows. The farm in question was situated in a distant colony, where many of the principles set forth by the author have been in use for years. Although much that is in the paper will not be new to Colonial farmers and engineers, I can assure the author that it will be very much appreciated by them, on account of the sound practical information regarding the actual design of the apparatus involved, which must have been collected as the result of a careful study of practice in other countries, and of painstaking experiment and first-hand experience. I have been much impressed by the apt provision of numerical data at just those places where figures are of especial assistance. Nowhere has the author been unreasonably sanguine, or advocated far-fetched schemes. It is perhaps unfortunate that the alphabetical arrangement of Table 2 gave such unmerited prominence to electrical book-keeping, which may give the impression that the paper is of an unduly visionary nature. This item has been dealt with last in the detailed treatment of the subject, and the author has there made out a good case for its inclusion, as a purely subsidiary matter. On page 725 the whole subject has been divided into electric driving of machinery, and electro-culture. Regarding the former as applied to farming, there can surely be no doubt at this date as to its advisability. Although this may not be self-evident to everyone from home practice, the fact that a Colonial farmer can work his land with labour receiving several times the wages obtaining in this country, meet the expenses of a long ocean transport, and then undersell the local producer, should indicate that mechanical agriculture is worth while. It is noteworthy that although English electrical engineers who own farms may be content to employ only the traditional methods, a Colonial farmer who knows little of electricity will practically always utilize it as soon as he has facilities for doing so. Recently a canvass was made in a farming area in New Zealand, of about 600 square miles, where hydro-electric power was about to be reticulated. It is significant that between 40 and 50 per cent of all the farmers included within the boundaries signed an agreement to take a supply as soon as it was available. In another part of the country a large hydro-electric scheme is coming into being for the benefit of what is almost solely a farming community. It was instituted and largely financed by farmers, who will themselves consume a large part of the initial output. Dealing with specific instances of electric drive, it should be easy to convince any farmer of the advantages of electric light, especially in outhouses and stables, where more harm has been caused by the striking of matches than conflagration, as the owners of nervous horses sometimes realize to their cost. Of the various farming machinery, those for milking, shearing, clipping, pumping, chaff-cutting, log-sawing, grinding, churning and separating are the most obviously adapted for electric drive, especially the first, since it is a regular morning and evening load. For working certain heavy machines, such as thrashers, which have to be transported from farm to farm, the mechanical tractor is at present at an advantage, as it can be used for haulage and then for operation. The portion of the appendix dealing with electric ploughing I have found very interesting, and I consider the author's advocacy of the roundabout system to be justified. I should like him to give a few details as to how the anchoring is effected, whether by stakes or by some more mechanical method. The author has shown electro-culture to be simple of application in the case of growing crops, and there seems a great probability that it will fulfil the hopes of its advocates. If so, it

is difficult to exaggerate its importance. A 20 per cent benefit due to its use would render possible the increase of the country's internal food supply by this amount, and that without any increased expenditure in preparation of the ground. From a national point of view, the whole subject of the paper is of especial importance at the present time. The international situation has deprived us of a market for our electrical manufactures. The same cause has cut off part of our food supply. By developing along the lines of the paper we can at once provide a new market and increase the home production of food. Thus the present unfortunate industrial conditions can be alleviated; and at the same time renewed prosperity can be conferred upon the rural industries.

Mr. R. Borlase Matthews (*in reply*): Probably this is both the first and the last time that a paper will be given at this Institution, in which an attempt is made to cover the whole field of electro-farming. The subject has now become so important, and so much experience is available, that the way is already open for the specialized paper. The cinematograph films and the lantern slides shown at the reading of the paper, together with the data given in it, afford abundant evidence that electricity is already very largely in use on farms. This view is supported by the significant fact that, since the war, the electric motor manufacturing departments of Continental companies have supplied far more than half their output for use on farms —and this amounts to many hundreds of thousands of kilowatts per annum. In California alone over 600 000 h.p. is now directly employed on agricultural work. In one week this year a German firm despatched 160 electric ploughing equipments from their works. Hence the practicability of using electricity on farms cannot be questioned.

Such comments as have been made on the paper seem to indicate that further detailed information is required concerning:—

(*a*) the finance of farming;
(*b*) the best form of power for farm purposes;
(*c*) the factors bearing upon the possibility of supply of current from central and private electric plants; and
(*d*) technical data concerning: (i) distribution of current on the farm, (ii) ploughing, (iii) hay-making, (iv) thrashing, (v) milking, and (vi) electro-culture.

Accordingly, the author proposes to supplement the paper with additional data on these points.

(*a*) *Finance of farming.*—It is not generally realized that the greatest wealth of every country in the world (including Great Britain) is obtained from agriculture. As matters are arranged nowadays, however, it is not the farmer, but the middleman, who takes the lion's share. He will continue to do so until the farmer becomes less suspicious of his farmer neighbours and takes matters into his own hands. To-day the small farms pay because of the long hours worked by the farmer and his family; and the large ones are profitable on account of the larger turn-over. It is significant that, of all trades and industries, the farmer most rarely appears among the lists of bankrupts. Hence a consideration of the applications of electricity to farming is really a question as to whether the profits on an already profitable business can be increased. Comparison with all other businesses indicates that this should be the case; and this view is supported by the farmers who already use electricity.

It is the little expenses that mount up in any business, and hence, even if a portion of each labourer's time can be saved by employing electrical drives, it must add to the total profits and therefore is worth consideration.

A well-organized farm of fair size, say 150–500 acres, equipped with modern appliances should pay a dividend of from 15 to 20 per cent upon the capital invested. If the farm specialized in products in which there was no foreign competition, it should pay anything in the neighbourhood of 50 per cent. As a matter of fact, many small farms pay considerably more than the latter figure, but the total capital is too small to make the return appreciable. It would seem that, given a certain area of land, the farmer must arrange his farming so as to obtain the maximum return. In a few very exceptional cases, in the hands of exceptional men, as much as £1 000 per acre has been made on intensive work. It has been estimated that nine-tenths of the farmers of this country are in competition with the rest of the world. In view of the cheap ocean freights which are available for foreigners, and the heavy handicap of excessive rail charges and taxation with which the home farmer has to contend, it is obviously the wiser policy for the majority to consider the class of farming adopted by the minority. In any case the intelligent use of electricity on a farm will considerably assist in more intensive farming—which immediately increases the profit per acre. If electrically operated machinery that saves half the time of a labourer is introduced, obviously additional work should be given to him. This involves a certain reorganization of the usual farm routine, but the extra profit available makes it worth while.

Farming is a class of business which appears to operate in a 10-years' cycle, which includes one or two years of extraordinary profits and a similar period of bad losses, with an interregnum of average results. On the complete cycle the results are good, and the author's opinion is that the applications of electricity will do much to aid the farmer in circumventing the bad seasonal conditions of which he so complains at present.

While it is perfectly true that to make money one must spend money, it is fully realized that many businesses have to be carried on with insufficient capital—and farming is often one of these. If the majority of farmers were to keep better accounts they would be better able to finance their farms. One of the great objections raised by the uninitiated is that an electric equipment means the spending of more money. Now most farms are so badly engineered that in many cases a new farm could be electrically equipped by an experienced engineer, at very little more than the cost of the existing equipments on other farms; and certainly there would be a great reduction

in the running and labour costs of the electrically equipped farm. As an approximation, the additional cost of electrification of a farm not within reach of a central station supply is usually equivalent to the cost of a generator, plus 50 per cent of that cost (say £200 on a 300-acre farm). This is on the basis that electric motors cost less than oil engines, and hence wiring and lighting accessories can be included. Unfortunately, a second-hand oil engine fetches very little money, as purchasers are always doubtful as to its condition—this is by no means a good testimonial for these engines. This often results in a loss of capital when a change-over is made. A useful approximation to the cost of the usual equipment for a mixed farm is £20 per acre. The cost of an equipment in which everything suitable was electric and on modern engineering lines would not exceed £25 per acre; though if only the most important things were electrically operated the total cost could be kept to £20 per acre. However, the annual savings and increased output would justify the higher figure. The foregoing remarks apply to a mixed farm, as the electrical equipment of a farm naturally depends upon the kind of work carried out upon it.

On the basis of credit for selling some of the unsuitable existing plant, the average mixed 300-acre farm could be electrically equipped for about £600. A 600-acre farm could be fitted out for about £1 100 on the same basis. A small farm of under 150 acres without an electric plough would require about £1 capital per acre. To modernize an existing equipment is always very different from starting out with an entirely new installation. The net result of expending this new capital would mean an increased annual profit of about £300 per annum on the 300-acre farm; on the farm of under 150 acres a return of about three-fourths of the capital invested per annum; and on the 600-acre farm a return of about £650. If weather were adversely to affect neighbouring farmers, these profits might easily increase by 50 per cent, due to hay-making, corn-sheaf drying, ploughing, etc., being carried on by electrical means, regardless of weather conditions, i.e. what would otherwise be losses are turned into gains. The above figures indicate an enormous return on the extra capital expended, and in a bad year would make all the difference to the balance sheet of the farm.

The author, after reading the paper, was questioned as to the size of the smallest farm that he had seen electrically equipped, and replied that he knew of several of about 24 acres. This seems to indicate that on the Continent, at any rate, no farm is too small to benefit from the use of electricity.

(*b*) *Power for farm purposes.*—It is generally admitted that a large amount of power is used on a farm in the course of a year. Obviously, therefore, the question as to what form of power should be employed is a very serious one. Though still largely employed on the Continent, mules, oxen and donkeys as farm draft animals have been largely superseded. In England the horse is in universal use, aided nowadays, very largely, by the oil tractor and steam plough. It is improbable that the horse will entirely disappear, though he is a costly animal to keep. At Greater Felcourt Farm in 1919, without any overhead charges, the cost per horse, including a proportion of the driver's time, worked out at £147. This compares with the figures of those well-known agricultural writers, Fream and Parkside. Electricity at 2s. per kilowatt-hour would have been far cheaper than horses, for work to which it would have been applicable. On a small farm where an electric supply is available, one horse should suffice, and on a 600-acre farm the number should not exceed two or three (three horses are kept on the author's 600-acre farm, and it is hoped shortly to reduce this number to two). The work should be so organized as to employ these horses as fully as possible, and the balance of the work should then be carried out by power. It is not a sound principle to reduce the number of men; rather the object of each farm should be to increase the output and the profits by farming more intensively. It has already been stated that nine-tenths of the farms in this country compete in growing products in competition with the world, hence their fortunes must vary with those of the world. Therefore it is very important that in spite of high taxation, high railway rates and high costs, the output should be a maximum at a minimum cost. Cheap and suitable power will, in the future, render considerable assistance in this direction, and experience shows that a great deal of this power should be electrical. It has been said with perfect truth that the losses of an ordinary farm in the course of a year would, if saved, make a good profit. These savings can be best effected by the judicious application of electrical methods, for in this way there will be the double gain of lower cost and improved working efficiency. The farmer is not going to use electricity because he loves it, but because he finds it will do the work he requires more cheaply, more effectively and more quickly. Also, it will enable him to circumvent adverse weather conditions. No line of business is successful unless it is progressive, and the applications of electricity will afford the opportunity of carrying out the work in improved ways. One speaker in the discussion referred to the necessity of going over the land eight times with horses for the preliminary cultivation work, but with mechanical power five or six times suffices; this alone means a considerable saving of time and cost.

The so-called handy little oil engine (already obsolete on Continental farms) has been advocated as a substitute for the electric motor, but the author knows, to his cost, a good deal about such engines. In a farm labourer's hands they are not nearly so convenient as the manufacturers' catalogues would appear to suggest. In the course of a year the total time taken in tinkering with such engines, the cost of repair parts, and the loss of time in getting work done, etc., amount to quite a serious figure. Assuming an electric motor to cost £20, 10 per cent or £2 per annum, or less than 1½d. per day, should cover interest and depreciation. This is equivalent to a man's time for the best part of 48 hours—much less than he would lose in looking after an oil engine for a year. In fact, this amount would not cover the cost of merely starting the engine when it was in good order.

While the British farmer is far ahead of his Continental neighbours in animal breeding and pasturing, he is far behind in intensive agriculture and the use of electricity. Enormous scope still exists for improving farming by attention to important details. It will be easier for the farmer to take up improved methods if at the same time he makes use of what is to him a new power, i.e. electricity, because it facilitates the handling of his very conservative men, as the author has discovered in many instances.

(*c*) *Load factor.*—The author is convinced, from his investigations of Continental practice that, if the work of ordinary mixed farms were to be rearranged, and all suitable applications of electricity were to be employed, a very good load factor could be easily obtained. In the early stages, however, it would be difficult to convert some of the farmers to these modifications—unless, of course, the rate charged by the central station were more attractive on a better load factor, when cost would soon settle the matter. On a 150-acre farm, as mentioned on page 730, a 1-h.p. motor can drive the barn machinery. The author suggested that a 3-h.p. motor would be preferable for chaffing, and in fact for other work when the farmer developed his use of power. This illustrative statement has been taken rather literally, as the load has been worked out as $1\frac{1}{2}$ hours' use of the maximum load per day, whereas it should be about $4\frac{1}{2}$ hours, as based on normal farm experience. This in itself compares quite favourably with many industrial conditions. In one scheme prepared by the author for operating with water power, multiple-way switches were employed, so that the power was always used for one of four purposes, i.e. cooking, heating, water heating, or motor driving (lights were provided independently). This gave a load factor of very nearly unity, and did away with the necessity of providing an expensive governor for the turbine (as a further refinement it was proposed when, say, only half the power was required for cooking, to switch the balance on to water heating). Hence, under the condition that the price per unit is low, a small farm can offer an ideal load factor. During the late winter and spring months the poultry section of a modernly equipped farm will provide a 24-hour load for the incubators and brooders. A large dairy farm consumes a great deal of hot water and steam, and there is no reason why this should not be produced by electrical means off the peak, if the price per unit is low enough, which will further improve the load factor of the farm. On the Continent it is quite a common practice to incorporate some form of rural industry during the winter, so as to increase the profits and keep all the work-people fully employed. This procedure again helps in obtaining a good load factor.

Through a misconception, several speakers did not appreciate that the author's suggestion on page 729, for carrying out thrashing operations in two stages, was another step in improving the load factor. Instead of thrashing continuously, the work is intended to be done by one or two men in their spare time. This is already the custom in some parts of Scotland, where the labourers thrash by artificial light in the early mornings until they can start work out of doors.

A somewhat difficult query has been put forward, asking for the probable load factors of a 300- and a 600-acre farm, as, of course, the term "farming" covers such a wide field of work. Some of the essential data are given on pages 729, 730 and 731. Different farmers will have different ideas as to the most suitable equipment for their work. On an intelligently equipped farm a load factor of 33 per cent may be anticipated. The following table gives some idea of the load factors for some typical cases :—

Approximate Load Factors for Electrically Equipped Farms.

Type of farm	Load factors	
	Farm only	With addition of farm-house lighting, cooking and part heating
	Per cent	Per cent
Dairy ..	13	24
Mixed ..	15	25
Arable ..	31	33

Note.—The load factor of wood-working factories is 5 per cent, and that of engineering works 6 per cent. Printing works have a load factor of 8 per cent, while cloth factories have a load factor of 10·25 per cent.

Since the size of farms in any neighbourhood varies considerably, it is useless to make the assumption that, if a 600-acre farm has a demand of 25 kW, the central station demand will be 25 kW per square mile. In any event the supply undertaking would run their lines along the route of the maximum demand, and Continental experience shows this practice to be advantageous in units of 50 kW. Further, farms cannot be considered apart from rural industries and the varied demands of even small villages in the same neighbourhood.

A difficult problem to solve is that of the policy to be recommended to the tenant farmer. It is not unlike the electric lighting problem of the rented town house. To meet this difficulty the author has devised a standardized, removable wiring system that comes under the description of a tenant's fixture. He also advocates the use of unit drives for the machinery, and portable motors, thus eliminating countershafts and similar fixtures. It rarely happens that a good farmer is turned out of his holding, and of course it is the more skilled class of agriculturist who would install an electric drive. In the event of a sale of the property, the farmer would lose only the poles for the overhead distribution (which are often taken as trees from the farm land).

[*d* (*i*)] *Distribution system.*—Reference has been made to the difficulty of arranging the distribution system on a farm, more especially for the field work. This of course requires very careful consideration, but is not so

troublesome as might at first be anticipated. To begin with, since each stationary ploughing gear has to be brought into only one corner of the field that it has to plough, it is merely necessary to bring the distribution lines within reach of the plough flexible electric cable, which is usually over 100 yards in length. Permanent lines are justifiable if operations other than ploughing are undertaken. However, on the Continent, to economize in copper the posts and insulators are installed permanently, and the copper lines are moved about as required. The author has one transmission line crossing his farm, and has planned one other line at right angles to this. He hopes that this simple arrangement will be sufficient for all the farm field requirements.

On the Continent it is usual, largely on account of the many old thatched buildings that still exist, to run the cables in galvanized steel tubes under the eaves outside the buildings. The author's method is to employ a bare-wire overhead ring main encircling the farm buildings, and to tap off this at convenient points, with insulated conductors attached to the line by a special fitting of his own design.

[*d* (*ii*)] *Ploughing.*—On the assumption that it would cost as much to carry out the various farm operations by electricity as by horses (which is far from being the case) many farmers still entirely overlook the value of time, and talk of ploughing a 10-acre field in 10 days *if* the weather allows. This work could be done electrically in two days (it would be less than half a day's work for a big electric set) in almost any weather. The biggest electric ploughs and their tackle can be moved from field to field in less than half a day (some have petrol motors for transport purposes incorporated as part of their construction, as mentioned on page 737).

It has been suggested that two motors should be employed on the same drive, in the case of 80–100-h.p. electric ploughing sets, so that the motors could be used for other work when not required for ploughing. As these sets could be used only for contract or co-operative work, since they are capable of ploughing 1 800 to 2 700 acres a year, it is hardly worth while removing the motors, as they would be in use over such a large portion of the year. Steam ploughing sets are usually set apart for their particular work only, notwithstanding their great capital cost.

Many consider a stationary electric plough gear with its two drums to be more complicated than the Fowler system. This is not so in practice as each of the double winders is provided with similar cable drums.

A question was raised in the discussion as to the practical possibility of utilizing portable trolley wires for electric ploughing. Several such methods have been tried, but without much success. One objection is that such equipment cannot be left to the management of a farm labourer, but necessitates the regular attendance of an electrician.

In the case of roundabout systems of ploughing, the methods of forming the anchorages have greatly improved since the days of the Howard steam system. The general principle now adopted is based on the stockless anchor of a modern steamer. The equivalent to the flukes is, however, separate, and consists of pointed angle-irons. These irons are driven into the ground separately, through a special frame (which serves as a stock). When it is desired to take out the anchor, a trip is knocked out on the stock; a strain is then put on the rope by the haulage gear, the anchor opens out and is thus easily pulled out of the ground. The cost of electricity per acre for ploughing would be from 1s. 2d. to 1s. 8d. (at 1d. per unit), as against paraffin at 3s. 6d.—7s. 6d. A peasant-farmer, who does not appreciate the value of his time and that of his team, can often be got to plough an acre for 25s.—this price, cheap though it is, gives a good idea of the economy of the electric method. The author is only just installing his first electric plough, and therefore can speak only of what he has seen of the experience of others in this matter.

[*d* (*iii*)] *Hay-making.*—An opinion has been expressed that, with large stacks of hay, difficulties would be encountered owing to the formation of mould, etc. Since reading the paper the author has successfully made hay from green grass built into three large stacks of about 20 ft. wide by 25 ft. high and of a considerable length, as soon as it was cut. His previous experience had been only with small quantities of grass. This large-scale trial naturally brought out a number of points that needed attention, but the author's conclusion, after doing the work, is that it could be done by any farmer with proper instructions, and, further, that hay of more uniform quality could be obtained than with the haphazard conditions that have been employed from time immemorial. The blowing need not be continuous, and there is no need of night-shifts if the stack is properly built and the electric fan is of correct size, although overtime may often have to be worked up to, say, 10 p.m. during the couple of days taken by the process.

On some farms of, say, 300 acres, hay-making often occupies 14 days. This period could be reduced to 4 days if the hay were carted green to a stack and cured in the stack by aid of an electric fan. The transport costs would be higher, but the total man-hours and horse-hours would be lower. Similar remarks apply to reaping.

[*d* (*iv*)] *Thrashing.*—From the author's experience of thrashing operations, a self-contained electrically-driven thrashing machine will save much time and money in shifting about and lining up. The author is at present fitting his thrashing machine on to a Tillings-Stevens petrol-electric chassis, so that in carrying out contract work on other farms thrashing can be started immediately the equipment arrives at a farm and gets alongside the stack to be thrashed. When an electrically operated thrashing machine has done its season's work the motor can be removed and used elsewhere. This would overcome any fears that it would, if left on the thrasher, get dirty and require too much attention. On a modern, electrically equipped farm, power plugs are fitted in various convenient positions about the stack yards, thus solving the apparent difficulty foreseen by some speakers. In many cases temporary lines are run to outlying stack yards on permanent posts and insulators.

In France the author has seen a large English

thrasher, electrically driven, operated by a woman, with a man in attendance to lubricate, attend to belts, and generally to see that the machine was working properly. The sorted, cleaned grain was taken away by electrically operated belt elevators to automatic weighing machines which discharged the grain into a granary. The chaff and cavings were blown by electric fans into store barns, and the straw was blown by another electric fan into a straw barn. Carters brought the sheaves to a level above the thrasher, and threw them down on to the feeding platform. Those who have had experience of thrashing on an English farm know what a number of men are needed, and hence the electric drive mentioned above is an excellent illustration of the labour that may be saved by a proper electric equipment.

[*d* (*v*)] *Milking.*—A question has been raised concerning the fat content of milk produced by a mechanical milker. It is not the author's experience that there is any difference. Mechanically milked cows give about 2 per cent more milk if the machines are properly adjusted. No machine will completely milk out a cow, and what are known as the "strippings," or last rich portion of the milk (about $\frac{1}{4}$ pint) have to be drawn by hand. This hand-stripping supplements the massage effect of the machine. It is very important to adjust milking machines properly or else various troubles will arise, for many of which the machines are often blamed.

Attention has been drawn to the possibility of using electric fans in the cow house. The author has never seen this application in practice, though he considered it at one time for getting rid of the flies at milking time. Flies not only irritate the cows but are likely to contaminate the milk.

[*d* (*vi*)] *Electro-culture.*—The suggestion for experimental work in stimulating the ground before it is cropped is most interesting, but hardly comes within the scope, as yet, of practical applications of electricity to farming. In Germany, weak direct current has been tried and it is claimed successfully by connections between the stems of vines and the ground.

Some idea as to the monetary value of the increased crops obtainable would, it is understood, be of interest. Some figures are given in the above table.

Much more could be stated concerning the particular aspect dealt with in this paper, i.e. the modernization of the world's oldest industry, viz., agriculture. However, space is limited, and sufficient matter has been collated to assist others in developing this new, though now well-established, aid to the farmer in his work, and this will benefit not only him individually, but also, through him, the rest of the world, which ultimately depends upon the efforts of his class. It is very fitting, therefore, that this Institution should do its share in facilitating the progress of the farmer, by showing him how he can best take advantage of the many and various economic applications of electricity.

TABLE OF REPRESENTATIVE RESULTS OBTAINED WITH ELECTRO-CULTURE.

Crop	Normal, unelectrified crop per acre	Increased crop per acre when electrified	Authority	Increased value of electrified crop per acre (on pre-war average prices)
		per cent		£ s. d.
Wheat	35 bushels	39	Newman	3 0 0
		29	Newman	2 4 0
		38 (straw 41)	Rothamsted	2 18 0
		49 (straw 88)	Blackman	3 15 0
Oats	40 bushels	30	Dudgeon	2 2 0
		49	Dudgeon	3 9 0
		50	Dudgeon	3 10 0
		57	Dudgeon	4 0 0
Barley	40 bushels	35	Rothamsted	1 15 0
		19	Rothamsted	0 19 0
Peas	27 bushels	20	Lemström	2 16 0
		28	Lemström	3 18 0
Potatoes	6 tons	37	Dudgeon	11 0 0
		15	Dudgeon	4 10 0
		50	Newman	15 0 0
Carrots	10 tons	50	Newman	15 0 0
Mangolds	20 tons	25	Newman	4 0 0

The normal four-course farm rotation is: (1) Wheat, (2) roots, i.e. mangolds, potatoes, etc., (3) barley or oats, and (4) clover, or peas, beans, etc.

The six-course rotation practised on Greater Felcourt Farm is: (1) Wheat, (2) mangolds and swedes, (3) peas and oats for hay, (4) wheat, (5) oats, and (6) grass.

PROTECTIVE APPARATUS FOR TURBO-GENERATORS.

By J. A. KUYSER, Member.

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SUMMARY.

The paper deals briefly with the causes of breakdowns in turbo-alternators, particularly in the stator winding, and discusses means for limiting damage in case breakdowns do occur.

Some of the systems of alternator protection which are at present in use are dealt with briefly and their advantages and disadvantages pointed out, particularly as regards protection for faults between turns of the same phase winding. A new system of protection is proposed which has the advantage of protection against faults between turns. The system has been tried out in the factory, but the author recommends that it be tested under actual operating conditions.

An investigation has been made of the phenomena occurring when the field circuit is opened, and it is shown that it is permissible to open the main field circuit without any discharge resistance. Different methods at present in use of opening the main or exciter field are discussed, and it is shown that they unnecessarily prolong the discharge of the field and the destructive effect of the fault currents. It is therefore recommended that a simple circuit breaker without discharge resistance and operated directly by the fault-current relays be provided in the main field circuit.

INTRODUCTION.

The increase in size of distribution systems, power plants and generating units has brought forward many new problems in the protection of supply systems and plant in the case of faults. Many improvements have been made in oil switches, automatic tripping devices and in the arrangement of protective reactances to control and limit the large amounts of power which have to be dealt with in the case of faults on modern large stations. Recent papers* on this subject indicate that, so far as the distribution system is concerned, satisfactory protection can now be obtained. Until recently it has not been possible to secure the same degree of protection on turbo-generators as on feeders and supply apparatus, but during the past year or two great advances have been made in generator protection, and it is the object of this paper to indicate the troubles which may arise and to describe the methods taken to avoid them and so minimize the damage in those cases where troubles do occur. It is an unfortunate fact that too frequently electrical breakdowns have occurred on large turbo-generators where the resulting arc has ignited the combustible material on the end windings or, if in the slot portion, has burnt the laminations, with the result that a complete rewinding and in some cases core rebuilding has been necessary. This results in a prolonged interruption of the supply, with the attendant loss of revenue in addition to the heavy cost of repairs.

It is impossible to stop a turbo-generator set quickly even when the steam is cut off and the vacuum broken, so that if the insulation of the stator end-connections takes fire, the fans supplying air at a high pressure convert the machine into a furnace, with the result that the temperature may be sufficient to crack the yoke casting which supports the laminations.

In some cases flames reaching to the roof of the power house have been observed. In such cases the insulation on one end of the stator windings is completely destroyed. A breakdown in the slot portion, while not so spectacular, may seriously damage the core and necessitate its rebuilding and rewinding. In these cases, if the machine could have been made "dead" *immediately* after the electrical trouble developed, and before the insulation became ignited or the laminations were seriously burnt, the damage could have been quickly and cheaply repaired. The cost of rewinding a 5 000-kW stator is of the order of £1 500, and the loss due to an interruption of several months in the supply may be many times this amount. The cost of complete protective gear as outlined in this paper, including an automatic field switch, is of the order of a few hundred pounds and therefore insignificant compared with its value as an insurance against loss.

The causes of electrical breakdowns, and recommendations for reducing the damage therefrom, are thus worthy of serious consideration by all engineers responsible for the operation of modern generating stations.

ELECTRICAL BREAKDOWNS IN ALTERNATORS.

The great majority of breakdowns in turbo-alternators are due to the following causes:—

(1) Faults between turns in the stator end-connections, or between conductors in the slot.
(2) Faults between phases on the stator end-connections.
(3) Faults to earth on the stator end-connections.
(4) Faults to earth in the stator slot conductors.
(5) Short-circuits or earths in the rotor winding.

The majority of serious breakdowns in turbo stators occur on the end connections. The following are some of the possible reasons:—

(*a*) The end connections are exposed to a number of deteriorating influences from the cooling air. Even if the air is cleaned by means of the wet air-washing apparatus at present in common use, an appreciable amount of dirt is often deposited in the course of time. In some cases free moisture has been carried over into

* See, for instance, A. E. MCCOLL: "Automatic Protective Devices for Alternating-current Systems," *Journal I.E.E.*, 1920, vol. 58, p. 535; also E. B. WEDMORE: "Automatic Protective Switchgear for A.C. Systems," *ibid.*, 1915, vol. 53, p. 157.

the machine, due to defective operation or the freezing up of air washers.

Another cause of trouble is the condensation on the machine of moisture from the atmosphere, due to the windings having a lower temperature than the air itself. This condition sometimes occurs when the generator has been shut down during the week-end and the atmospheric temperature has increased during this time. If no dampers are installed in the air ducts, air from the outside atmosphere may be drawn into the machine owing to the natural draught in the building, and deposit its moisture on the cooler generator surfaces. Large amounts of water have been found dripping from the winding or the core, and breakdowns have been traced to this cause.

(*b*) Due to their complicated shape, it is not possible to use the same high-grade insulation (i.e. moulded mica) on the end connections as on the slot conductors.

(*c*) In the bar and connector type winding, before the end windings are placed in position it is usual to apply between the different conductors in the same slot a high flash-test of 50 or 100 times the operating voltage between turns in order to eliminate faulty conductors. It is not possible to apply such a test between the stator end-connections when the machine is completely wound and all the series turns form a complete circuit. The only practical way to test between turns on the finished stator is to run the machine at the maximum overspeed and field current, when a voltage of approximately $1\frac{1}{2}$ times the normal value (or, say, 200 volts per conductor for an average size of machine) is obtainable. This voltage may not indicate weak parts in the insulation due to defective material or workmanship. Earths inside the slots due to the use of non-fireproof material which deteriorated under the high operating temperature have occurred on machines of older design. These faults have practically disappeared in modern machines where mica wrapping is used.

In some cases, however, the stator conductors have not been sufficiently braced at the point immediately where they leave the slots, and an earth has developed. This difficulty is practically overcome by the modern methods of bracing the winding.

In one case a machine of older design broke down due to the deterioration of the slot insulation owing to vibration. The clearance between the conductor and the laminations was in this case excessive and on no machine of modern design has this trouble been observed. In general it can be said that earths in the slot conductors have practically disappeared in modern machines.

Faults in the rotor windings are usually due to broken connections, to displacement of end windings caused by centrifugal force, or to the use of combustible insulating materials in the slots. As faults in rotor windings do not jeopardize the whole machine they will not be further considered in this paper.

Precautions for preventing stator breakdowns can be grouped as follows :—

(1) Care in design and manufacture.
(2) Installation of suitable air-cleaning apparatus.
(3) Care in operation.
(4) Protective reactances.

Generator Design.

Insulation.—The insulation should be able to withstand continuously the temperature, the dielectric stresses, and the mechanical stresses to which it is to be subjected.

As regards temperature, modern turbo-alternators are now insulated with materials which meet the requirements. The stator conductors are, as a rule, insulated by means of mica backed with a small amount of paper and moulded tightly on the bars (Haefely process). This insulation is of a permanent nature and will withstand temperatures of at least 150° C. The rotor is insulated by means of fireproof material only, e.g. mica, asbestos or similar materials. Excessive temperature-rise is therefore rarely the cause of breakdowns (in machines of modern design) as the new methods of insulation have appreciably increased the factor of safety, notwithstanding the fact that operating temperatures have been increased. Practically none of the breakdowns which have come to the author's knowledge had any relation to the temperature-rise. An examination of the winding after a failure showed as a rule that the insulation was in good condition and had not deteriorated due to excessive temperature.*

Bracing of the stator winding.—This is of the greatest importance. The end connections should be braced to prevent short-circuits between turns or phases. The stator slot conductors should be braced at the point where they leave the core, as a deformation at this point will cause the mica insulation to crack and result in a fault to earth. The insulation of the stator end connections is one of the most difficult problems. On account of the complicated shape of the connectors moulded-mica insulation as used for the slot conductors cannot be adopted and the insulation is invariably applied in the form of tape. It is difficult to fill the interstices between the layers of tape in order to guard entirely against atmospheric influences. Thus the end connectors which, as previously mentioned, are the most vulnerable portion of the winding, can be made reasonably safe by the liberal and careful use of tape and varnish. In all large machines the stator conductors are of such heavy cross-section that a solid conductor would cause excessive heating due to eddy currents, and generally the conductor must be divided into parallel laminations. In some types of winding the lamination is carried further than necessary to reduce the eddy currents to a reasonable value; this is undesirable, as the conductor is weakened and less able to withstand bending in case of short-circuits. A mechanically very strong winding is obtained by laminating the slot conductors and using solid copper bars for the end connections where no lamination is required. The slot conductors must in this case be twisted or transposed in the slot.

It is important that faulty slot conductors and end connections be removable with the minimum disturbance to the remaining parts of the winding. Specifications for turbo plant sometimes require interchangeability of individual coils, but it has not been sufficiently realized that this feature is of no avail unless protective

* Newbury, *Electrical World*, 1920, vol. 76, p. 58.
G. A. Juhlin: "Temperature Limits of Large Turbo-Alternators," *Journal I.E.E.*, 1921, vol. 59, p. 281.

gear is provided which will localize the damage and prevent the insulation of the whole winding being destroyed by fire.

Air-cleaning apparatus.—Various forms of apparatus have been devised for air cleaning. These may be divided broadly into two classes, i.e. dry filters and wet filters, the former being very costly in maintenance and presenting a considerable fire risk. The wet filter does not remove all the dirt and, unless carefully adjusted, may allow free moisture to pass into the machine. To avoid the serious objection to wet- and dry-air filters the air-cooling system has been developed. In this arrangement the air-circulating system is completely closed on itself. The air passes through the generator, where it is heated, then through a cooler where it is cooled, then again through the generator, and so on. By this means the only dirt that can be deposited in the machine is that contained in the original volume of air which fills the air-circulating system, and this amount is entirely negligible. Fig. 1 shows a sectional arrangement of generator and air cooler.

Care in operation.—Generators should be examined from time to time. Clamping bolts should be tightened and the windings thoroughly cleaned and re-varnished. Each manufacturer will supply detailed instructions for the care and maintenance of his machines.

Protective reactances.—The use of internal and external reactances for protective purposes is a big subject, and one which cannot be covered in this paper. It is sufficient to say that by their proper use the shocks on the generators may be greatly reduced.

In spite of every precaution which can be taken in the design and manufacture of turbo-generators, breakdowns will occur occasionally, and in such cases the best that can be done is to isolate the machine and to "kill" its field in the shortest possible time in order to limit the extent of the damage. If the protective apparatus supplied for this purpose does not function sufficiently rapidly to prevent the insulation on the end windings from catching fire, then means must be provided for extinguishing the fire.

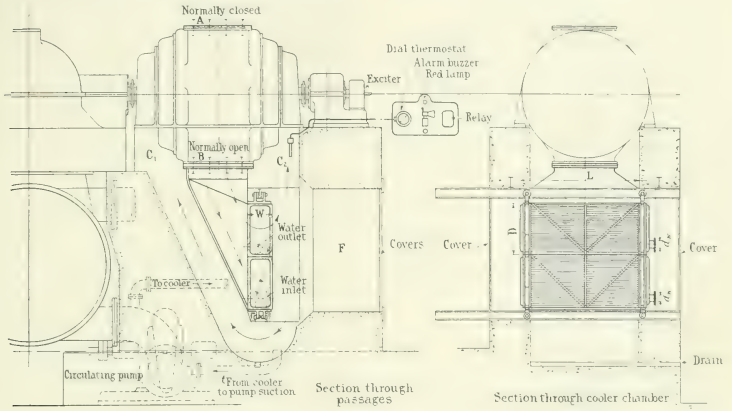

FIG. 1.

ALTERNATOR PROTECTIVE DEVICES.

The development of protective devices for alternators has probably been somewhat as follows :—

(1) Fuses, operating on overload only.
(2) Circuit breakers, operating on overload only.
(3) Circuit breakers, operating on overload and reverse power.
(4) Circuit breakers, operating on generator fault only and not on overload (balanced protection).
(5) Circuit breakers, and field switch operating on generator fault only and not on overload (balanced protection).

The last-named is the only protective system in which the generator field has been "killed" wherever the main circuit breaker has opened automatically, and marks a great advance, especially in the case of enclosed machines.

The following are the main requirements of modern electrical generator protective gear. The gear should operate on all possible faults in the generator or in the cables between generators and busbars, but should be inoperative for faults and short-circuits external to generator and cables. The gear should operate the main circuit breaker, interrupt the field current and

reduce the generator voltage to a small value in the shortest possible time. Further, it should not introduce in the system new weak points which are likely to increase the risk of breakdowns or cause unnecessary shut-downs.

The system most commonly used is the Merz-Price

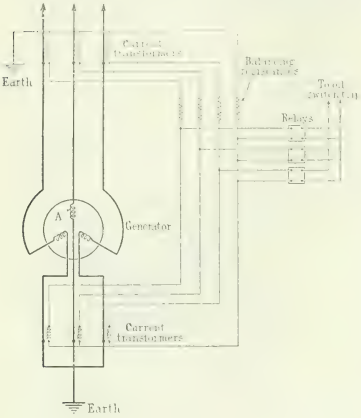

Fig. 2.—Protection of three-phase generator by Merz-Price (balanced current) system.

balanced protective gear. In this system (Fig. 2) two current transformers are inserted in each of the phase windings, one transformer being located at the terminals or the switchboard and the other at the star point. The transformer secondaries belonging to each phase are interconnected by means of pilot wires, and the tripping relay is connected between the pilot wires. The relay closes the tripping circuit for the main breaker and the field switch. The star point of the system must be earthed. It will be seen that the gear will trip for a fault to earth in the generator leads, or a fault between phases.

In the case of a fault between different turns of the same phase winding the fault currents are purely internal and will not cause unbalancing of the currents in the phase terminals. No protection is therefore obtained for such faults until they develop into an earth or into a short-circuit between phases. This constitutes the most serious defect in the Merz-Price system.

Another limitation of the Merz-Price gear is in connection with the current transformers and the earthing resistance. Two current transformers seldom have identical magnetic characteristics, and perfect balance is therefore seldom obtained; also a heavy magnetization due to a short-circuit on the system may upset the magnetic balance. This defect is evident on heavy overloads, and trouble has been observed due to the gear tripping the machine in the case of short-circuits on the system. To overcome this difficulty the setting of the relay must be made very coarse, and in some installations it has been found that a setting of 100 per cent of the full-load current is necessary. Improvements have recently been made in the relays, and the relay setting can now be reduced to 15 per cent or less. The disadvantage of coarse relay settings is that the earthing resistance must have a very low value, or the star point must be directly connected to earth, so that in case of a fault to earth the fault current will be sufficiently large to trip the gear. Cases have been known where the generator developed an earth not far distant from the star point and the Merz-Price gear failed to operate, resulting in the destruction of the winding. Assume for example that the relay is set at 15 per cent and that an earthing resistance is used which will pass 30 per cent of normal load current in the case of an earth on the terminals; if now an earth develops at a point A (Fig. 2) located 40 per cent distant from the star point, the fault current will be 12 per cent, or less than the current required to operate the relay. Consequently, all parts of the winding between the star point and point A, or one half of the winding, will be unprotected in the case of faults to earth.

If the star point is earthed directly without an earthing resistance full protection can be obtained for the stator winding. In general, however, it is desirable to limit the fault current by a resistance, as even in the short period required to operate the gear (see Fig. 3) appreciable damage might be done if the full current were allowed to flow. The unprotected part of the winding is the part nearest the star point which has normally a low potential to earth and for this reason should be the least likely to fail. In practice, however, breakdowns near the star point have been observed and these require protection. Earths on the feeders

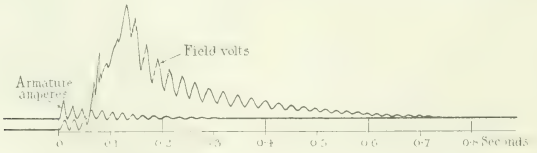

Fig. 3.—Oscillogram showing operation of relay-operated field switch.

may explain similar failures. If these occur the star point assumes a potential equal to the phase voltage, and an earth may occur at a weak point of the insulation near the neutral point.

It is therefore desirable that the unprotected part of the winding shall be as small as possible, say 5 per cent of the total winding. This can be effected by making the earthing resistance of sufficiently low value. For example, if the minimum setting of the relays is 15 per cent, and 5 per cent of the winding is allowed to be unprotected, the earthing resistance should be of such value as to pass 15/5, or 3 times full-load current for an earth on one of the terminals.

Self-Balancing System.

This system has recently been proposed by Mr. J. R. Beard to overcome some of the above-mentioned defects

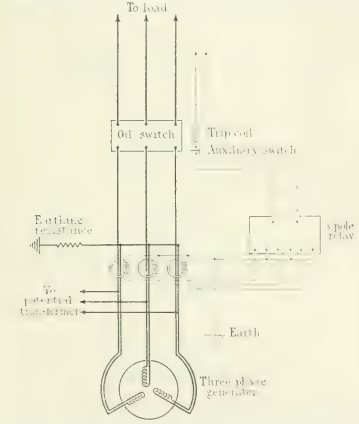

Fig. 4.—Self-balancing protective gear for a three-phase generator.

in the Merz-Price system and has been adopted in several power stations. Fig. 4 shows the arrangement. The two ends of the phase windings are carried through the same core, and a secondary winding on this core is connected to the relay. The advantage of this arrangement is that the current balance is obtained by means of a single current transformer, thus eliminating the difficulties in obtaining a perfect balance mentioned above in connection with the Merz-Price system.

The relays can be set to operate at their minimum current, and even if a relatively high earthing resistance is used the gear will operate on faults to earth although they may occur near the star point of the generator. The limitation to this device is the fact that in order to prevent complication of the gear a busbar-type current transformer is used to obtain the balance. With such a transformer the sensitivity is limited unless the out-of-balance current exceeds approximately 20 amperes. The self-balancing gear has some minor disadvantages compared with the Merz-Price gear from the switchgear point of view, but it gives better protection and is for this reason to be preferred for turbo-alternator work.

As regards faults between turns, the conditions are the same as in the Merz-Price gear and no protection for such faults is therefore obtained.

Mid-Point Protective Gear.

The author has devised a protective gear which will operate for all possible faults including faults between turns. Mr. J. R. Beard and Mr. A. Collins have been working on similar lines and have co-operated with the author in the development of the scheme. The general arrangement is shown in Fig. 5, from which it will be seen that the protected generator A, B, C, D is provided with tappings E, F, G from the mid-point of each phase. Reactance coils (or potential transformers) are connected in parallel with each phase and also provided with mid-point tappings M, N, O. The mid-point of the generator and that of the reactance coils are connected together. Current transformers are inserted in the mid-point connections and the secondaries of these transformers are connected to the relays.

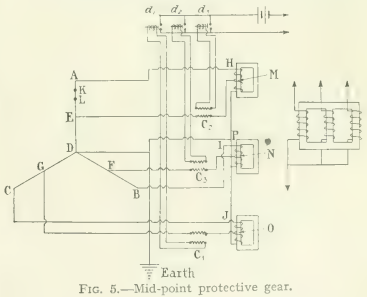

Fig. 5.—Mid-point protective gear.

When the machine is in normal operation the interconnected points of generator and resistance are at the same potential and no current will flow in the mid-point connections. If a fault occurs between turns, for example between points K and L (Fig. 5), the number of active turns between points A and E will be reduced and at the same time the flux will be weakened by the demagnetizing action of the fault currents. Both actions will reduce the voltage between A and E and, to a smaller extent, the voltage in ED. The voltages in AE and DE will therefore be different, whereas the voltage of HM and MP will remain equal, being generated by the same flux. A current will therefore flow in the mid-point connection EM. The voltage and current induced in the mid-point connection is used to operate a tripping relay (by means of a transformer).

The unbalancing of the voltages in the phase halves

or the shifting of the mid-point in the generator phase winding occurs not only on a fault between turns but also when a fault occurs to earth or between phases. For example, a fault to earth at K (Fig. 5) will circulate a large current in KD which will reduce the voltage of DE to a greater extent than the voltage of AE. The same will be the case for a fault from K to any point of the other two phases.

The system will therefore deal with any fault in the generator winding, including faults between turns, and will give more complete protection than has hitherto been obtainable.

It will be seen that a fault outside the generator, for instance in the cables leading from the generator, will not cause unbalancing, and the generator leads would therefore not be protected. To include the leads in the protection, the cables can be provided with a conducting shield surrounding the central core and

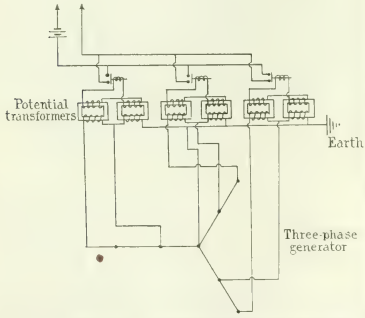

FIG. 6.—Method of connecting potential transformers in mid-point protective gear.

insulated for half the phase voltage from the core and from the armour. This shield is connected to the mid-point at the generator end. The reactance coils in this case are located at the switchboard and their mid-points connected to the shield. It will be seen that a fault from one of the cores to earth must be preceded by a fault from the core to the shield which forms the mid-point connection, and such a fault will operate the gear.

The generator winding has in this system to be provided with three tappings insulated for 50 per cent of the generator voltage, and three terminals for the mid-point connections, which carry normally no current and can be of very small section. It is not necessary to bring out the 6 phase leads as in other systems; the star point can be made in the stator winding and the generator therefore requires only 4 main leads and 3 small pilot leads.

Instead of installing separate reactance coils the potential transformers which are usually required in connection with the voltmeters and wattmeters can be provided with tappings and used for the protective gear. A convenient arrangement is shown in Fig. 6. In this arrangement two potential transformers are required per phase, the secondaries of which transformers are connected in opposition in series with the relay. Special secondary windings are provided for the instruments. As regards the sensitivity and the operation for faults to earth near the star point, this gear is similar to the self-balancing gear in so far as no operation is to be feared for heavy overloads and the relays can be set to their maximum sensitivity. The limitation for dealing with these faults is therefore determined only by the sensitivity of the relays, the impedance of the reactance coils, and the amount of resistance between the neutral point and earth. This will be understood from the following explanation. If a fault to earth occurs at point E (Fig. 5), it will short-circuit E and D, and also that part of the reactance

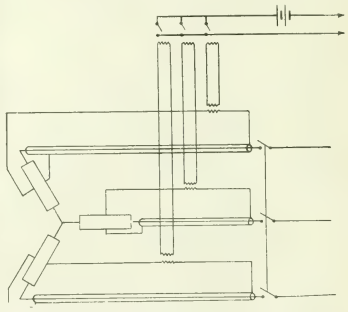

FIG. 7.—System of internal protection for alternating-current apparatus connected in two parallel circuits.

coil lying between M and P through the relay. The other part of the reactance coil HM is still supplied with voltage from AE. The reactance coil operates therefore as a short-circuited transformer, HM being the primary and MP the secondary, and the current in the relay will depend upon the reactance between the two halves of the winding HM and MP and upon the impedance of the relay circuit. The leakage in the reactance coil can, if desired, be made very small at slight extra expense by special arrangement of the windings, and this method is therefore to be recommended if high earthing resistances are used. As an alternative, the size of the reactance coil can be somewhat larger than that of an ordinary potential transformer to obtain a small impedance.

A simplification of the described arrangement can be made in the case of a generator where the phases are wound in two parallel circuits (Fig. 7). In this case the mid-points of the two parallel windings can be interconnected over the transformer which operates the relay. This system is very limited in its application,

as few generators are wound in two parallel circuits, this being desirable only for extremely large currents. Further, it would be limited to 4-pole and 2-pole machines wound with concentric winding, as in 2-pole machines wound with involute or basket-type winding (similar to a d.c. armature) the mid-points in the windings of each pole are not equipotential. In some cases, however, the active conductors are divided in two parallel conductors lightly insulated from each other, and the parallel circuits are continued throughout the winding and twisted in the centre of the winding to avoid eddy currents. In such case equipotential mid-points can be created without great difficulty by omitting the twist in the centre of the winding and substituting two other twists, located half way between the mid-point and the extremities of the winding.

Fig. 8 shows an application of the mid-point protective gear for two a.c. generators running in parallel. This arrangement has the disadvantage that two machines are tripped out when a fault occurs. The sound machine would, however, be immediately ready for synchronizing. This disadvantage would perhaps

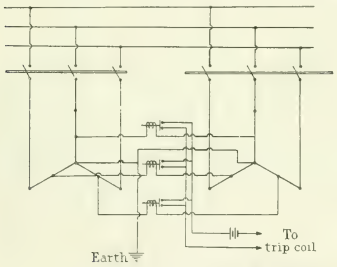

FIG. 8.—Mid-point protective gear for two alternators in parallel.

not be important in a station where a large number of machines run in parallel. The great advantage of the arrangement is that extremely little gear is required, i.e. only three current transformers and relays for each pair of generators.

AUTOMATIC FIELD SWITCHES.

As previously mentioned, a complete generator protective equipment should include an automatic field switch to interrupt the field circuit immediately the fault occurs. This field switch, so far as the protection of the generator is concerned, is as important as, if not more important than, the main switch.

The automatic field switch can be located in different parts of the field circuit and can take the form of :—

(1) A switch in the exciter field circuit.
(2) A reversing switch in the exciter field circuit.
(3) A circuit breaker in the main field circuit.
(4) A switch to short-circuit the slip-rings and exciter.

Hitherto, in order to limit the voltage-rise on breaking the induction circuit, it has been standard practice to provide a non-inductive field-discharge resistance or "kicking coil" where a field circuit was to be opened. The normal operation of the field-discharge switch is to connect the field winding in parallel with the discharge resistance and to open subsequently the current supply from the exciter armature. Thus, after the switching operation the field circuit is not interrupted, but the current circulating through the winding and the resistance is allowed to die out gradually. The ohmic value of the discharge resistance is, as a rule, roughly equal to the field resistance.

It is of great interest to study the phenomenon of field discharge in detail. The general formula which applies in the case is

$$E = -L\frac{dI}{dt} = -n\frac{d\phi}{dt}10^{-8} \quad . \quad . \quad . \quad (1)$$

therefore

$$L = n\frac{d\phi}{dI}10^{-8} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where I = current in amperes,
R = total resistance in circuit,
L = self-induction coefficient in henrys,
t = time in seconds, and
n = effective total number of turns in the rotor.

As regards the self-induction coefficient L, it is perhaps worth while to point out that a misleading definition is often given in literature and text-books, namely:—The self-induction coefficient is equal to the number of line linkages per unit of current; a qualifying statement usually being added to the effect that this applies only to circuits having no iron. This definition has frequently led to error when applied to problems similar to the present example, the mistake being made that L was determined as a variable by taking corresponding values of ϕ and I, which method gives absolutely incorrect results. It is proposed to replace this definition by the following, in accordance with expression (2):—The self-induction coefficient of a circuit at a given current is equal to the rate of change of the number of line linkages with respect to the current. This definition is applicable to all circuits, and L can be introduced as a variable quantity in the case of circuits containing iron.

For our problem we can determine $d\phi/dI = \tan\alpha$ (curve 2 of Fig. 9) by drawing tangents at different points of the saturation curve and determining for each point $(d\phi/dI)$, $L = (d\phi/dI)10^{-8}n$ and L/R. After having determined the curve for L/R it will be possible to construct the discharge curve from the following consideration.

For any point of the curve we obtain :—

$$IR = L\frac{dI}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\frac{L}{R} = -I\frac{dt}{dI} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Expression (4) represents the length of the subtangent at the point in consideration. The subtangent at any point of the I curve is therefore equal to the momentary

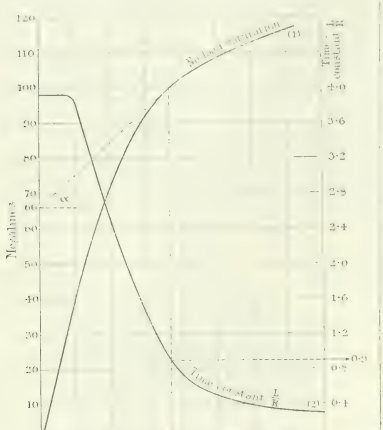

FIG. 9.—Characteristic curves of turbo-alternator.

value of the time-constant L/R. We can therefore determine the tangent on the I curve for the moment of switching off by setting off the subtangent L/R

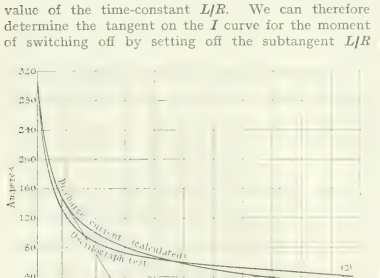

FIG. 10.—Discharge current of turbo-alternator with discharge resistance equal to field resistance.

corresponding to the initial maximum current. Identifying a small part of the tangent and the curve we can find a second point of the I curve, from which a new tangent can be drawn, using the new value for L/R. Continuing in the same way the whole curve can be determined point by point.

As an example we may take a 7 500-kVA, 3 000-r.p.m. turbo-alternator. Curve 1 in Fig. 9 shows the no-load saturation curve. The stator has 40 series turns per phase. The rotor has 324 turns (total). The field resistance is 0·44 ohm, and the discharge resistance 0·38 ohm.

Curve 1 (Fig. 10) has been determined from these data and checks sufficiently closely with the oscillograph test (see Fig. 11) which is replotted to a different scale in curve 2 of Fig. 10. As will be seen from this curve, the self-induction coefficient L varies in the ratio of 0 to 3·25 approximately, for different values of the current, and this explains the rapid drop in current for the initial part of the curve.

Some factors have not been taken into consideration in this method—for instance, the damping currents in the rotor body, the distribution factor of the rotor winding, and the field leakage. The influence of the damping in the rotor will be considered later, whereas the other factors can be taken into account by adding or subtracting a percentage to ϕ as calculated from the saturation curve.

Time Required for the Field Discharge.

Oscillograms taken on turbo rotors, and calculated curves show that an appreciable time elapses before the field current has decreased to a reasonably small value. From Fig. 12, which refers to an 8 900-kVA, 25-period, 2-pole machine, we find that the time taken to reach a field current of 10 per cent of the no-load value is approximately 11 seconds. In this test the main field circuit was interrupted and a discharge resistance equal to the rotor resistance was used. For a 23 500-kVA, 25-period, 2-pole generator of recent design, the time to reach 10 per cent of the normal field current would be approximately 30 seconds, or 1 minute if the exciter field instead of the main field circuit were opened.

It is evidently necessary in the case of a stator breakdown that the voltage shall disappear as quickly as possible, and the present arrangements therefore appear to be unsatisfactory. The discharge is too slow and the voltage is maintained for a sufficient period to cause appreciable damage. This is confirmed by experience. The first remedy for this sluggishness suggested by the previous considerations is to use a high discharge resistance. It is obvious from the formula that the discharge time is inversely proportional to the total resistance in the discharge circuit. If, for example, a resistance of 19 times the rotor resistance is used, the total resistance will be increased in the ratio of 1 : 10, compared with the usual arrangement of a resistance equal to the rotor resistance, and the rapidity of the discharge will be increased in the same proportion.

A danger to be feared from the use of such high discharge resistances is the high voltage-rise on the rotor winding during the switching, and this, therefore, requires investigation. After the discharge switch in the main field circuit has opened, the field current does not disappear immediately but is maintained at its full value for a short period, and this, circulating

through the discharge resistance, will cause a reversed slip-ring voltage equal to the ohmic drop in the resistance. If, as is usual, the discharge resistance is equal to the field resistance, the voltage-rise is equal to the excitation voltage, but if a high discharge resistance of, say, 19 times the field resistance is used, the voltage-rise would be theoretically 19 times the excitation voltage.

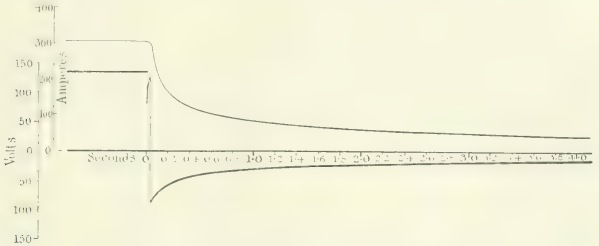

FIG. 11.—Oscillogram of discharge current on a 7 500-kVA, 3 000-r.p.m. turbo-alternator with discharge resistance equal to rotor resistance.

For a generator having an excitation voltage of 50 at no load the voltage-rise at no load when opening the switch would be $19 \times 50 = 950$ volts. If the machine is loaded the field current and the excitation voltage are appreciably increased; the flux and the stored magnetic energy will, however, be only slightly increased and the voltage-rise on full load would therefore not be appreciably greater than at no load. For the purpose of the investigation the excitation voltage is therefore always understood to refer to no load on the generator.

INFLUENCE OF DAMPING CURRENTS IN ROTOR BODY.

The next factor to be taken into consideration is the damping action of the closed circuits formed by the rotor slot-wedges and the rotor body. The effect of the damping currents is, first, to reduce the high voltage-rise if a high discharge resistance is used, and, secondly, to retain to a certain extent the sluggishness of the discharge. The damping circuit may be represented by a separate field winding short-circuited on itself, having the same number of turns as the field winding and lying in the same slots. If the resistance of the main field is equal to R_f, the ohmic value of the discharge resistance to R_r, and the equivalent resistance of the damping circuit to R_d, then the equivalent resistance of the two circuits combined will fulfil the conditions

$$\frac{1}{R_e} = \frac{1}{R_f} + \frac{1}{R_r} + \frac{1}{R_d}$$

The equivalent resistance R_e determines the discharge current and voltage. R_d can be determined experi-

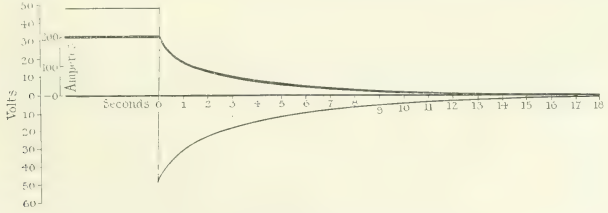

FIG. 12.—Oscillogram of discharge current on an 8 900-kVA, 1 500-r.p.m. turbo-alternator with discharge resistance approximately equal to rotor resistance.

mentally by making two discharges for different values of R_r and recording the current/time or voltage/time curves. The oscillogram shown in Fig. 13 was taken on the same rotor as was used for Fig. 12, the discharge resistance being 30 times the rotor resistance, or $R_r = 30R_f$, whereas, in Fig. 11, $R_r = R_f$. Comparing the two tests we find that the time to reach a certain percentage of the maximum voltage is in the ratio of 9 : 1, the rapidity of the discharge being increased

9 times. The resistances R_e will therefore be in the same ratio, i.e.

$$9\left\{\frac{1}{31R_f}+\frac{1}{R_d}\right\}=\frac{1}{2R_f}+\frac{1}{R_d}$$

or $R_d = 38R_f$ approximately.

The damping circuit of this rotor has therefore an effect equivalent to a discharge resistance of 38 times the rotor resistance. If the rotor were open-circuited without a discharge resistance a voltage-rise of 38 times the excitation voltage would therefore be expected. The oscillogram reproduced in Fig. 14 was taken under this condition, i.e. the rotor circuit was directly open-circuited by means of an ordinary circuit breaker without any discharge resistance, while the normal field current was flowing. The observed voltage-rise was 25 times the excitation voltage. This voltage is lower than would be expected from the previous comparison of time-constants, due to the fact that the circuit is not interrupted instantaneously, the arc persisting for a fraction of a second, and the flux is already somewhat reduced when the arc finally breaks. The reduction in the voltage-rise due to this reason may be taken as roughly 25 per cent.

It will be observed from Fig. 14 that after the rotor circuit has been open-circuited without discharge resistance, the voltage across the slip-rings does not disappear, but a voltage of opposite polarity to the normal excitation voltage appears and dies out rapidly. This voltage indicates that after the current has been broken a rotor flux still exists, and is being maintained by the currents circulating in the damping circuit. The time required for this flux and the remanent voltage to disappear depends on the value of the resistance R_d in the damping circuit. By noting the time required for the remanent slip-ring voltage to disappear, we can obtain a value for R_d. A comparison of Figs. 12 and 14 on this basis gives $R_d = 35R_f$, which is roughly in agreement with the figure previously found.

It should be noted that the rotor of this machine was built up of 2-inch plates shrunk on a shaft, spaces being left between the plates. This explains the high resistance of the rotor body.

Similar tests were made on the previously mentioned 7 500-kVA, 3 000-r.p.m. turbo-alternator having a rotor of the solid forged type provided with radial ventilating ducts. The tests reproduced in Figs. 11, 15 and 16 were taken for $R = R_f$, $R = 20R_f$ and $R = \infty$ respectively. The value of the damping circuit resistance

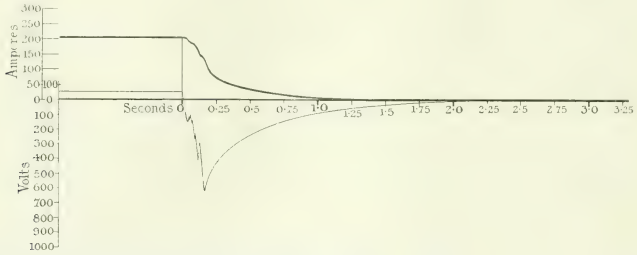

FIG. 13.—Oscillogram of discharge current on an 8 900-kVA, 1 500-r.p.m., 25-period turbo-alternator with discharge resistance equal to 30 times the rotor resistance.

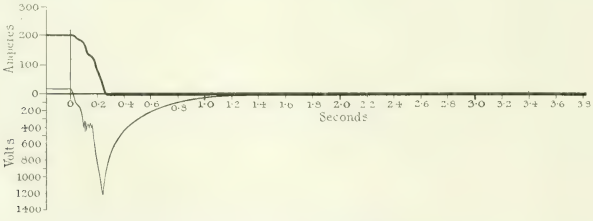

FIG. 14.—Oscillogram of discharge current on an 8 900-kVA, 1 500-r.p.m. turbo-alternator with no discharge resistance, i.e. rotor open-circuited.

determined from these tests is roughly 5 times the rotor resistance, indicating that the rotor built up of plates has a resistance roughly 7 times greater than that of a solid rotor.

No tests have been carried out on rotors built up of thin laminations. These rotors will probably, as regards the resistance of the damping circuit, be fairly

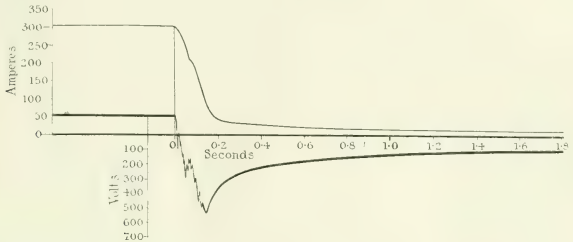

FIG. 15.—Oscillogram of discharge current on a 7 500-kVA, 3 000-r.p.m. turbo-alternator with discharge resistance equal to 20 times the rotor resistance.

similar to a plate rotor. In both types the damping currents will to a large extent circulate in the squirrel cage formed by the metallic slot-wedges, and the coil-retaining rings.

For rotors of the solid type we may assume $R_d = 5R_f$ (approx.) and if the rotor is wound for 125-volt excitation at full load and 60 volts at no load, the voltage-rise between the slip-rings would be roughly 250 volts, or

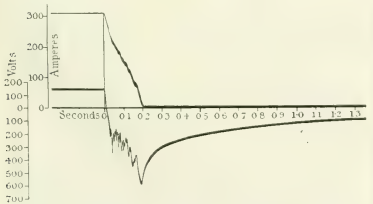

FIG. 16.—Oscillogram of discharge current on a 7 500-kVA, 3 000-r.p.m. turbo-alternator with discharge resistance equal to infinity, i.e. rotor open-circuited without discharge resistance.

500 volts if the rotor were wound for 250-volt full-load excitation.

The 7 500-kVA, 3 000-r.p.m. solid rotor gave a maximum voltage of 600 volts for a field current considerably in excess of the normal value.

The test illustrated in Fig. 14 was taken on an 8 900-kVA rotor built up of plates, and shows the highest voltage-rise observed on any of the tests. The actual peak observed was 1 200 volts measured between the two slip-rings, and the maximum voltage to earth would be one-half this value, or 600 volts, neglecting asymmetric capacity and insulation resistance. For a solid rotor of average output or size the figure would be 150 to 250 volts. This is an unexpectedly low value in view of the opinion generally held, i.e. that a break in the main field circuit would cause such an excessive voltage-rise as to lead to a certain breakdown. It is usual to test the field winding and the exciter circuit at 2 500 or 3 000 volts (R.M.S.) a.c., equivalent to a d.c. voltage to earth of 3 500 or 4 200 volts, and this test will therefore give a large margin of safety for any voltage-rise which would occur during operation of the protective gear. The discharge resistance which has hitherto been used in conjunction with automatic field switches is therefore unnecessary, there being no danger of an insulation breakdown if the main field is opened by means of an ordinary circuit breaker. It has been shown earlier in the paper that the discharge resistance has the undesirable property of preventing the rapid discharge of the field in case of a fault, and these resistances may therefore be omitted altogether for new installations; also those resistances which are already installed may be disconnected. This applies to machines having rotors of the solid cylindrical type. No investigations have been carried out on laminated rotors, but it will no doubt be permissible to follow the same course with these. As a precaution it may in these cases be desirable to make a trial during which a needle spark-gap is connected across the slip-rings. The needle gap should be set to operate at about 1 500 volts or over, according to the voltage at which the rotor has been tested. If no discharge takes place across the needles when the field is opened, the discharge resistance may be taken out of circuit. If a discharge takes place, indicating that there is practically no damping effect in the rotor, a discharge resistance is necessary to reduce the voltage-rise to a safe value. The voltage-rise between the slip-rings for a rotor without any damping effect may be estimated as being approximately equal to 0·8 (no-load field current) × (discharge resistance). A slip-ring voltage of 1 000 or more would generally be permissible.

The elimination of the discharge resistance will

greatly increase the value of the protection obtained, save the unnecessary expense of resistance units and special switches, and reduce the number of moving parts, thus increasing the reliability of the switch.

Automatic Field Switch in Exciter Field Circuit.

In the previous considerations the field switch has been assumed to be located in the main field circuit. Another method which is frequently used is to provide a small automatic switch in the exciter field circuit.

If the exciter field is opened, the exciter voltage disappears fairly rapidly even if a discharge resistance is used, as the stored energy in the exciter field is small compared with the copper loss in the exciter field winding. After the disappearance of the excitation voltage the main field current continues to circulate until the large amount of magnetic energy in the alternator field has been dissipated. The field winding during this time is practically short-circuited on itself, and the resistance in the discharge path would be one-half the amount which would be in circuit in the case of a main field switch and a 1 : 1 discharge resistance. The time of the discharge being inversely proportional to a 1 : 1 discharge resistance. For a 23 500-kVA, 25-period alternator of recent design the discharge time to reach 10 per cent of the normal voltage would be roughly 60 seconds.

Automatic Reversing Switch in Exciter Field Circuit (Suicide Connection).

In this method the field circuit of the exciter is opened and subsequently reversed. The reversal of the field has the advantage over the previous method that the remanence of the exciter is destroyed, and the remanent voltage on the a.c. terminals reduced. The discharge time depends only upon the total resistance in the discharge path, and in this respect there is no advantage compared with the simple exciter field switch. An oscillogram was taken with this connection, the other conditions being the same as in the oscillogram (Fig. 17). The discharge curve was found to be identical with the latter oscillogram and is therefore not reproduced.

An advantage could be obtained from the use of a reversing switch, by exciting the exciter field coils separately from an independent source and allowing the exciter to generate reversed voltage. The maximum

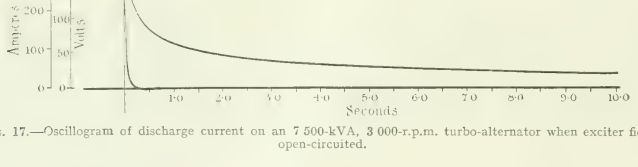

Fig. 17.—Oscillogram of discharge current on an 7 500-kVA, 3 000-r.p.m. turbo-alternator when exciter field is open-circuited.

the total resistance, the discharge would therefore be twice as long.

It is generally advisable to provide direct-connected exciters with a series winding supplying a small percentage of the total ampere-turns. This winding has the effect of making the exciter more stable in the case of rapid variations of the exciter field rheostat, and prevents loss of field and reversals of polarity on the exciter. If such compound-wound exciters are used in connection with an exciter field switch the series winding has an additional retarding influence on the field discharge, which will therefore be extremely slow. In one case where this arrangement was adopted on a large unit, severe damage resulted to the stator winding and core during a stator breakdown.

Another minor disadvantage of locating the field switch in the exciter field circuit is that, due to the remanence of the exciter field, the main current is not quite interrupted and the alternator voltage cannot be reduced below approximately 5 per cent.

The oscillogram (Fig. 17) shows a field discharge on the previously mentioned 7 500-kVA rotor, the exciter field being opened. The discharge time to reach 20 per cent of the normal voltage is approximately 10 seconds, which is roughly twice as long as on the oscillogram (Fig. 11) taken with a main switch and reversed voltage obtainable would be approximately $1\frac{1}{2}$ times the full-load excitation voltage, or 4 times the no-load excitation voltage. We have seen that the opening of the main field circuit produces an instantaneous reversed slip-ring voltage. This reversed voltage is, at the moment of interruption, usually greater than $1\frac{1}{2}$ times the full-load excitation voltage but decreases gradually towards the end of the discharge.

The main field switch therefore produces a more rapid reduction of the current during the first period of the discharge, whereas the separately-excited reversed exciter would give a more rapid reduction for the final part of the discharge. The most rapid discharge could therefore be obtained by the following sequence of operations :—

(1) Open-circuit the main field.
(2) Simultaneously reverse the separate excitation of exciter.
(3) Close the main field again as soon as the reversed slip-ring voltage has dropped to a somewhat lower value than the reversed exciter voltage.
(4) Open the main field as soon as the a.c. voltage or the a.c. fault currents (not slip-ring voltages) have dropped to zero, to prevent building up the main field in the reversed direction.

A system of quick-acting relays could be arranged to obtain this result, but it is not likely that the advantage obtained would warrant the use of such complicated gear.

Slip-Ring Short-Circuiting Switch.

Another method of interrupting the field current is to establish a dead short-circuit between the two slip-rings. This will short-circuit the exciter armature, and some sparking will therefore occur on the exciter commutator unless a preventive resistance is used. This sparking is, however, not very severe and is of short duration, as the exciter immediately loses its field. From this point of view the method is quite practicable. The disadvantage lies rather in the fact that the resistance in the discharge path is smaller than in any other method, and the discharge time correspondingly lengthened.

The slip-ring short-circuiting switch has been used in practice in the method illustrated in Fig. 18. The automatic switch consists of a single-pole double-throw switch in the main field circuit. Normally the exciter armature is connected directly to the slip-rings, and the resistance R is short-circuited. In the operating position the slip-rings are short-circuited and the resistance is connected in series with the exciter armature. The exciter field is also short-circuited, and the exciter therefore is de-energized. The "loading resistance" eliminates sparking on the exciter commutator.

A disadvantage of this method, as previously explained, is the sluggishness of the field discharge. Due to the fact that no external resistance is inserted in the main field circuit during the discharge, the discharge time is practically the same as for a switch in the exciter field circuit.

The following table of data in regard to the previously mentioned 7 500-kVA, 3 000-r.p.m. turbo-alternator gives roughly the relative time of the field discharge for the different methods of connecting the switch :—

Method	Relative Time	Pressure between Slip-rings
		volts
Main field broken..	1	— 300
Ditto, but discharge resistance equal to field resistance ..	4	— 50
Exciter field opened or reversed	8	0
Slip-rings short-circuited.. ..	8	0

Method of Tripping Auto-Field Switch.

The field switch can be tripped in different ways, the following being those more usually adopted :—

(1) Direct from the fault-current relays.
(2) By means of an auxiliary switch on the main a.c. circuit breaker.
(3) By means of a combination of methods (1) and (2).
(4) A time-lag may be introduced after the tripping of the main switch.

If all apparatus belonging to the protective system could be absolutely depended upon, there is no doubt that method (1) would be preferable, on account of the more rapid action. It happens sometimes, however, that the relays operate for a fault outside the generator, due to faulty adjustment, or, if reverse-power relays are used, these may operate for a failure in the motive power. In these cases the field switch would be tripped and, if we assume further that the main breaker fails to operate due to a defect in the tripping mechanism, the sound machine will remain connected to the system with the field out of circuit. It is often assumed that such an operation contributes a grave danger. As a matter of fact, nothing serious happens if the field circuit of one of several parallel-running alternators is interrupted for a short time. The alternator if of the cylindrical type will operate as an induction generator, and increase its speed slightly, thus losing part of its watt load. The current drawn from the system will be mainly a wattless magnetizing current and this will cause a voltage-drop on the system. This voltage-

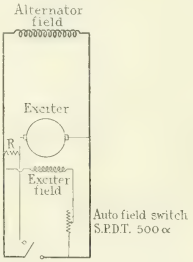

Fig. 18.—Automatic field-suppression. Slip-ring short-circuiting system with exciter protection.

Note.—R is a loading resistance, not to be less than about 50 per cent of the main field resistance for momentary service.

drop will be severe only if the affected machines constitute a large percentage of the total plant capacity. The increase in speed can immediately be detected by the ear, due to the beats produced by the interference of the machines running at slightly different speeds.

A case has recently come to the author's knowledge where the field of a 23 500-kVA alternator was interrupted due to an accidental opening by hand of the exciter field circuit. The machine was at the time operating in parallel with other plant of a capacity roughly equal to its own capacity. The current drawn from the line was observed to be approximately 60 per cent of the full-load current, which corresponds to the magnetizing current operating as an induction generator; no other serious disturbance occurred. Other similar cases have occurred on sets of smaller capacity. It might be worth while to mention here that neither reverse-power relays of the usual type, nor balanced-current relays, will operate in the case of loss of field, as has sometimes been stated in literature and patents on this subject.

The next possibility is that in the case of faults

occurring in the machine the main a.c. breaker fails to open. If the field is not interrupted the system will feed into the fault, as will also the defective generator itself. If the field is interrupted the faulty machine will not contribute to the fault currents. The energy flowing into the fault, and the damage, will therefore be appreciably reduced, particularly if the faulty machine is large compared with the other plant in parallel with it.

The object of method (4) is to prevent large voltages being induced in the rotor due to the inductive effect of the fault currents in the stator. For the same reason it has also been proposed to connect overtension devices between the rotor slip-rings. Experiments carried out by the author on a machine with a solid rotor have shown that the voltages induced in the rotor in the case of a stator fault are of even smaller magnitude than those observed for a direct opening of the main field circuit under no-load conditions, and therefore not of a dangerous nature.

The conclusion is, therefore, that operation directly from the fault-current relays (method 1, see Fig. 19) is the most satisfactory method, although there would not be much to choose between methods (1), (2) or (3) if the main breaker is very quick-acting and is periodically tested to eliminate all possibility of "sticking."

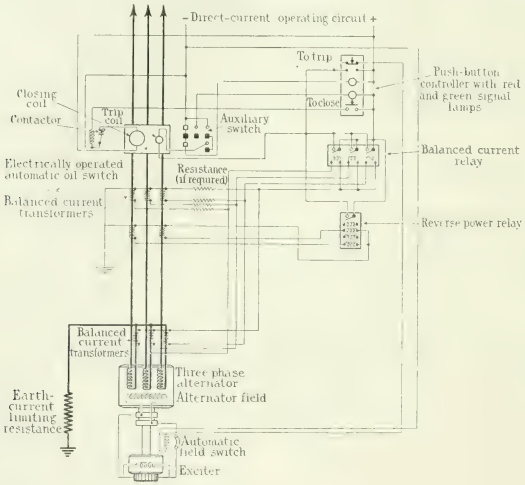

FIG. 19.

EXTINGUISHING OF FIRE.

Although the installation of electrical protective devices greatly reduces the possibility of fire in the windings, it is still advisable to provide means for extinguishing a fire in the extreme case of the protective gear failing and the winding becoming ignited. The usual method of extinguishing is to apply a hose or a fire extinguisher through the inspection covers in the stator end guards. This is a very drastic method and should be used only as a last resort; also there is usually so long a delay in applying the extinguisher that the winding is ruined. If serious damage is to be prevented extinguishing must be done *immediately* after the accident and preferably automatically by the action of the fault-current relays, and an extinguisher must be used which will not ruin the insulation. It is sound practice to provide air dampers in the air inlet and outlet, which are automatically closed by means of solenoids energized from the protective relays.

Fig. 20 shows the arrangement adopted for a 15 000-kW set. A point which requires attention on these dampers is the leakage, as the volume of air normally circulating is so large that even a small part of it is sufficient to sustain a fire which has been well started. As soon as the dampers are closed the air pressure generated by the fans rises considerably, as shown in Fig. 21. It will be seen that the pressure rises from a normal value of 7 inches to a maximum of 15 inches if the damper is completely closed. The dampers must therefore be made to fit well; also the generator casing and end guards should be designed for as small clearances as possible. It is highly probable

that many air dampers, particularly in the case of large machines, would fail to extinguish a fire on account of excessive leakage.

Another advantage of dampers in the air ducts is that the air circulation can be positively stopped while the generator is not in operation, thus preventing condensation of humidity due to the natural draught in the building. Such condensation may also take place when a cold machine is started up and the air temperature is above the temperature of the machine. When this condition occurs it is therefore advisable not to open the dampers before starting up, but to leave the dampers closed until the generator has attained a temperature above that of the cooling air.

In addition to the use of air dampers some engineers strongly recommend the provision of pipes inside the end bells, through which steam may be turned upon the windings. This method is being employed by several power-station engineers, more particularly on the Continent and in the United States, and seems to give good results. Interesting data on this subject are given by M. A. Savage in the *General Electric Review*, Jan. 1918. In this article tests made to investigate the effectiveness of extinguishing by steam are described. The general conclusions reached are that steam will extinguish any fire due to burning insulation, providing the following recommendations are followed :— The leakage of the air dampers should be less than 10 to 20 per cent. A sufficient volume of steam should be admitted to displace the volume of air contained in the machine. Outlet dampers are more effective than inlet dampers. The insulation when properly dried out will not be materially damaged.

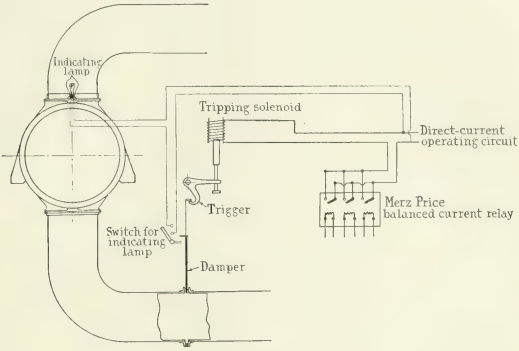

FIG. 20.

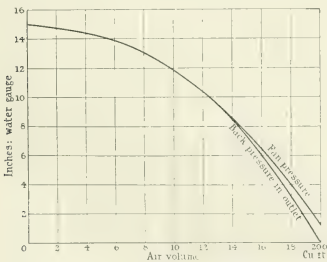

FIG. 21.—(Air pressure)/(air volume) curve for a 5 000-kVA, 3 600-r.p.m. turbo-alternator.

The author is of opinion that such a system of steam pipes can be recommended. The only doubtful point is the influence of the hot steam on the insulation. It is not likely that the condensed steam can penetrate very far into the interior of the insulated windings, and a thorough drying-out after the application should remove all moisture. The temperature of the steam cannot rise above 100° C. after expansion through the nozzles, and this temperature cannot harm the insulation. Arrangements should be made to prevent any steam leaking past the inlet valve during normal operation. This can be effected by providing two

The method is also being used by the Duquesne Light Co., Pittsburgh, U.S.A., on some 18 000-kVA, 12 000-volt machines. This company reports that during a peak on the system it has been possible to put a machine back on the line after a fire without shutting down the steam end or examining the winding. This method of procedure would, however, not be recommended generally, even by the strongest advocates of the system.

interlocked valves in series and a water drain between the two valves. A tell-tale hole should be provided between the valves to detect any leakage of the first valve. It is not advisable to operate the steam valves automatically from the Merz-Price relays, as only in case of actual fire is their operation required. It would, however, be possible to install thermo-electric relays in the generator and operate the valves from these. In this case, however, there is still a possibility that the steam jets may be operated by an accidental closing of the relays.

Instead of using steam it is, of course, possible to use water, and some engineers prefer this. The author believes, however, that the steam is likely to do less damage to the generator than is the water.

The difficulties of extinguishing fire are practically eliminated when the circulating system is used, as the amount of air available for sustaining the combustion is limited. For a 12 000-kW generator the total volume of air in the circulating system would be approximately 1 500 cubic feet. The total weight of combustible material on one end of a generator of this size would be approximately 400 lb. To burn completely this weight of material would require approximately 30 000 cubic feet of air, i.e. approximately 20 times the volume actually present. Thus it would appear that if there is no great leakage of air into the system, the burning cannot be very extensive. Damage due to the electric arc would, however, continue until the field was "killed," and the generator disconnected from other running machines.

Conclusions.

(1) In spite of every precaution which can reasonably be expected, breakdowns will sometimes occur in the insulation of a.c. generators.

(2) A comparatively small electric arc may set fire to the combustible material on the end windings. This fire being fanned by the blowers will speedily develop into a general conflagration of the end windings, totally destroying the insulation and often doing other damage. If the fault occurs inside the core serious burning of the laminations may result, necessitating a complete rebuilding of the core.

(3) If the generator can be disconnected from the busbars and its field "killed" immediately after the fault occurs, ignition of the insulation and burning of the core laminations can usually be prevented. In such cases the damage is ordinarily of a comparatively insignificant nature, and can be rapidly and cheaply repaired.

(4) The balanced-current protection system is the simplest and most satisfactory one yet devised for operating the protective gear in the event of faults to earth, or between phases on a generator. Its weakness lies in the fact that it does not operate on faults between turns of the same phase. Such faults, if they do occur, will develop into an earth or fault between phases.

(5) The protective system proposed by the author and Mr. J. R. Beard operates under all fault conditions, but it introduces certain complications in the auxiliary apparatus. The system has not yet been tried on a scale sufficient to recommend its general adoption at the present time. It is recommended that the system be installed on a few sets to obtain experience of its behaviour under actual operating conditions.

(6) The possibility of preventing extensive damage in the event of a fault occurring in a generator winding depends largely upon the speed with which the main circuit breaker can be opened, and the voltage reduced on the generator terminals. This necessitates opening the main field circuit of the generator.

(7) Calculations and tests show that there is little risk in opening the main field circuit even in the case of large generators. Currents set up in the field-circuit core body and in the slot wedges retard the collapse of the field to such an extent as to limit the induced pressure to a safe value. The various schemes proposed for opening or reversing the exciter field circuit or short-circuiting the main field give results many times slower than opening the main field circuit.

(8) There is no gain in interlocking the field switch with the main circuit breaker so that the former will not open if the latter fails to operate, for in the event of a fault less damage is likely to be done with the circuit breaker closed and the field switch open than if both remain closed.

(9) Inlet and outlet dampers should be provided in the air ducts. These may be arranged to close automatically in the event of a breakdown in the generator winding, and should be kept closed at all times when the generator is not in operation.

(10) It is sound practice to install steam pipes inside the end bells of generators, so that steam may be turned into the generator in case of fire. This operation should not be automatic, on account of possible damage to the insulation of the machine, and would be used only if a fire actually started.

(11) With the closed air-circulating system serious burning is not likely to occur, but protective gear should be installed to limit the extent of the electrical burning.

(12) A complete protective system for a turbo-generator set would consist of the following :—

Balanced protective gear.
Inlet and outlet air dampers.
Automatic cut-off valve on turbine, and vacuum breaker on condenser.
Main circuit breaker and field switch.
Steam pipes inside the end bells.

All the above safety devices, with the exception of the steam supply to the end bells, could, without risk to the plant, be made to operate automatically upon the occurrence of a fault in the generator.

It is questionable whether the complete protective system outlined above is necessary, as a fire can usually be prevented if the main field is "killed" instantaneously.

The author desires to acknowledge his indebtedness to Mr. J. S. Peck and several of his colleagues for valuable suggestions in preparing the paper, also to the Metropolitan-Vickers Electrical Company for permission to publish the information.

Discussion at The Institution, 27 April, 1922.

The President (Mr. J. S. Highfield): I am inclined to think that when we have papers on protective gear it would be very useful if we were given first of all some idea of the cost of the gear and, of far more importance, some information as to the value of the property that the gear is to protect. In ordinary electrical installation work there must be a great many thousand pounds' worth of material in the shape of gear installed to provide against faults that occur once in, say, 20 years. The protective apparatus described by the author is not of that class. We who have had experience with large turbine plants know what extensive damage results from accidents and, at the present time, although much protective gear is of great service, large improvements are required. Consequently, I am very glad that the author has raised this important question.

Dr. S. P. Smith: On the general question of protective apparatus for turbo-generators, I cannot say that I have very much sympathy with the author's views. I certainly can sympathize with the supply undertaking that wants to protect its machines and prevent damage to expensive cables; but, from the designer's point of view, I think that, as regards external faults, we ought to be able to design turbo-alternators which do not need protection. Protective devices may be necessary for cables, switchgear, etc., but it should be possible to have a dead short-circuit across the terminals of the turbo-alternator without injuring it, and station engineers will doubtless insist on this in the future. Of course, it amounts to this: we must be willing and ready to pay for reliability. We must not adopt as our ideal the American idea of what has been called "rapid antiquation"; but we must build machines that will last. Such machines must not be "cut" with regard to material, and the mechanical design must be particularly sound. With regard to internal faults, here again we must pay attention rather to reliability than to obtaining a machine that may soon be scrapped for something more efficient. Proper attention to mechanical details will do much to ensure the safety of the machine. I have not very much faith in the efficacy of breaking the field current rapidly, although it is doubtless well to break the exciting current when the fault occurs inside the machine, just as it is necessary to prevent power being pumped into a faulty machine from the busbars. The author admits that switching off the field current does not destroy the field, and it is this which causes the damage when once the short-circuit has started. The flux may persist for a considerable time—possibly for a minute. The length of time during which the flux persists inside the alternator determines, of course, how long the induced pressure and current continue; on which in turn will depend the safety of the machine in the case of internal faults. In connection with the time taken for the main field to build up or decay, the damping winding used in modern solid rotors plays an important part. It is necessary to make the joints in this winding as perfect as possible, and this again tends to retard the decay of the flux when the exciting current is interrupted. Therefore, whilst agreeing that it may be a very good thing to cut off the field current as rapidly as possible in the case of a fault, we must have more evidence as to the time taken for the flux to die away before concluding that the breaking of the field current will protect the winding from destruction.

Major K. Edgcumbe: I am pleased to notice that the author strongly recommends the breaking of the field by the relay instead of by the circuit breaker. I have always advocated that, my feeling being that it is better to take the chance of leaving the machine on the bars without its field than to have the certainty that valuable time would be wasted before breaking the field. That brings me to the question of what actually happens if the machine is left on the bars without its field. I have always understood that in this case it does not take a reverse current at all, but continues to supply current to the busbars at a low leading power factor. The author definitely states that the current flows in the opposite direction, but it is difficult to imagine what the turbine is doing under these conditions. It is certainly news to me that the voltage induced when the field is directly broken without any resistance is so remarkably small. I am not altogether convinced, however, by some of the curves. The author appears to think that all that is necessary is to reduce the current to zero. But is that really so? In Fig. 14, for example, after about 0·3 second the current is zero, but there is evidently a considerable flux still flowing in the rotor. The area of the curve to the right of any point really represents the flux still left in the rotor, and in Fig. 14 it seems that about half the initial flux is still there, although the current has been reduced to zero. What we want to know is not so much the time taken for the current to become zero, as the total amount of heat which the flux will generate in the stator, and I should imagine that this could be easily calculated from these curves. In Fig. 19 the author shows directional relays as an additional protection. He puts these reverse relays in only two out of three phases, but I feel that this is a mistake, as the extra cost of a third relay is negligible, and such a relay gives standard protection against faults between turns.

Mr. H. W. Clothier: Recent experience appears to have convinced the author not only that protection is necessary for the continuity of supply, but that it must be of a kind which will function expeditiously in order to save money in the cost of repairs. Thus he confirms the practice which switchgear and relay builders endeavoured to establish long ago. The user who is content to ignore these automatic protective devices on the ground that they are more bother than they are worth is, to say the least, taking unnecessary risks. The author has brought his experience to bear on three features: (1) the fault between turns; (2) the earth fault near to the neutral end; and (3) the extent to which an alternator will be damaged after being isolated by the oil switch, unless the alternator field is suppressed. Hitherto, with regard to the fault between

turns, with balanced systems of protection we have been satisfied to allow such faults to develop to leakage faults to earth. As to the earth faults near the neutral end, these may be so reduced in current amplitude by the neutral resistances as to be insufficient to operate the relays, and are inoperative until they develop into faults between phases. In Fig. 2 the author gives a case where the unprotected part is 40 per cent of the winding. The latter percentage depends upon the permissible setting of the relay and the amount of resistance inserted in the neutral. With a fault setting of 12 per cent I think that a resistance to pass 30 per cent of full-load current is too small. The proper way to shorten the unprotected part of the alternator winding is to use a larger neutral resistance, in order to increase the amount of current which it will allow to pass. It is a common mistake for these to be installed to pass less than full-load current, whereas twice full-load current would be better in most cases. Given a 10 per cent fault setting this would place point "A" only 5 per cent away from the neutral end, instead of 40 per cent as instanced by the author. If the fault current is so small that it will not operate relays under these sensitive conditions, it cannot seriously endanger the continuity of supply until it develops into a fault taking a larger current. Then the relays will operate. Sometimes the size of the neutral earthing resistance is unduly curtailed for reasons of economy, but it should not be so reduced as to interfere with the satisfactory design of protective equipment, and besides, due consideration is necessary for the protection on outlying feeders, some of which may require sufficient current to trip faults to earth on overload protection. I think that no serious case has been proved against the Merz-Price balance system or the self-balance system, but I agree with the author that the mid-point or between-turns system should be given a trial, and my company have already equipped a trial machine on the methods shown in Fig. 6. This will operate on a fault between turns which gives a potential difference of 40 to 50 volts between the two sides of the winding. I hope that this apparatus will be given a stability test on a 6 000-kW machine which is shortly to be subjected to a repetition of short-circuits. The objections to the system as I see them now are (1) the introduction of the potential element in the protective-gear transformers; (2) the extra tapping on the stator coils; and (3) the absence of protection for the alternator terminals. I believe, however, that all these can be successfully overcome by the careful design of detail parts. The insulation of the transformers must be made very sound, and with a much higher margin for safety than is usually allowed on potential-transformer designs. I am assured by two alternator makers that there is no difficulty in finding a suitable place for the tapping on the alternator winding or for taking a well-insulated conductor away from this place to a terminal. With regard to the protection of the terminals, the author's proposal to screen these and the cable by a mid-point connection to the switchboard depends for its success mainly on a good design of terminal box. I should prefer a compound-filled box mounted on the alternator frame, made to combine the high-tension and mid-point screen conductors. If the proposed screening conductor is objected to on account of the special cable involved, the alternative method for providing requisite protection against faults on the terminals would be to use, in addition to the mid-point protection system, a balanced leakage protection. The latter would consist of one set of three current transformers mounted on the switchboard and balanced through a pilot wire with a single transformer of the bar type threaded over the neutral conductor of the alternator. I feel that it is most important, that on all such protective systems there should be an ample margin in the sensitiveness of the relays between the test-room results and that promised or put into use in actual practice. Just as we have a factor of safety in the strength of a structure, so should we have it in reliability of operation. One way is to avoid reducing the earth resistance to too small an amount.

Mr. A. D. Sloan: I speak from a designer's point of view, and I am inclined to think that the author will largely agree with the remarks of Dr. Smith but, at the present time, accidents will happen because, while design has been greatly improved, it is not yet perfect. I should like to ask the author whether the protective gear he has devised in conjunction with Mr. Beard is sufficiently quick-acting to isolate an incipient fault before it develops into a fault to earth. It is interesting to note that the author considers it to be just as important to "kill" the field as to isolate the machine from the busbars. I can confirm his opinion that opening the exciter field is not satisfactory. On pages 769 and 770 the author quotes an example where the pressure-rise without using a discharge resistance is calculated as 38 times the normal excitation voltage. The observed voltage-rise, however, with the rotor winding directly open-circuited by means of an ordinary circuit breaker without any discharge resistance, was only 25 times the normal excitation voltage. The author suggests that the discrepancy is due to the current not being interrupted instantaneously, the arc persisting for a certain length of time. I should like the author to say if, in his opinion, a magnetic blow-out circuit breaker would cause the flux to be killed more quickly, and if the pressure-rise would still be within the calculated value of 38 times the excitation voltage. As to fire extinction, I have gathered from conversations with engineers in the United States that the opinions as to the merits of steam versus water spray are pretty equally divided, good results having been obtained by both methods. I should like to say in conclusion that while it is at present advisable to take every precaution to protect large turbo-generators, we must not accept complicated protective gear as the ultimate solution of our troubles, but rather continue to improve the reliability of the alternator. When one considers the progress made in this direction during the past 10 to 15 years it is not too much to hope that expensive protective gear is only a temporary expedient and may yet become an unnecessary insurance.

Mr. H. Brazil: The author's new proposal for protective gear is an interesting one, but I feel that the large number of additional potential transformers required constitutes a grave objection to the system.

Amongst supply engineers there is a general agreement that if an opportunity occurs to eliminate a potential transformer, that opportunity is taken. Mr. Clothier mentioned that this question has been brought up amongst designers, and they are confident they can provide the necessary insulation to ensure safety. I should like to point out, however, that the leads to the potential transformers—nine in all—are always a possible source of trouble, and also complicate the wiring considerably. The author states on page 765 that, in order to ensure protection against faults near the neutral point when the Merz-Price system is used, the earthing resistance should allow three times the full-load current of the generator to pass. When one considers the output of the generators that are now being installed, a resistance to pass this current assumes very large proportions, and I gather from this paper that the author's system of protection would enable this resistance to be made smaller. As there appears to be a considerable divergence of opinion on the question of the ohmic value of earthing resistances, I think it would be of great interest if the author would give his opinion as to what is the best ohmic value with his own and other systems of protection.

Mr. L. M. Jockel: I should like to mention one or two very practical considerations from the operation engineer's point of view. The system put forward by the author in collaboration with Mr. Beard is, I think, exceedingly ingenious and certainly worthy of proper research. On the other hand it seems to me, from an operation engineer's point of view, to be rather complicated, and that it will give rise to further capital expenditure in connection with the alternator itself than has been the case in the past, and, except in the case of very large machines, I am doubtful whether many practical engineers would care to install it, at any rate for the present. In my experience a fault between turns is usually never evident until it becomes a fault between phases or a fault to earth. I am not convinced that the protective gear will be so sensitive as to furnish the necessary indication so that the damage may be totally confined to between turns, and not to between phases or to earth. On page 766 the author says: "Instead of installing separate reactance coils the potential transformers which are usually required in connection with the voltmeters and wattmeters can be provided with tappings and used for the protective gear." I think that there are very few operating engineers in this country to-day who would countenance such an arrangement. It seems to me to be extremely bad from the point of view of reliability of operation, and it also has several other disadvantages which are more theoretical. My own experience has been that the fewer potential transformers there are in a power station the greater is the feeling of security. With regard to automatic field-breaking devices, my experience of the interlocked rotor circuit breaker and main oil switch has been very satisfactory. The author refers on page 772 to the loss of field on turbo-alternators. I know, from personal experience, that if the field entirely opens it can generally be closed again without taking the machine off the busbars or causing any very abnormal conditions. In one case in which four 1 500-kW machines were operating in parallel, the field of one set was completely broken and restored on two occasions. The only indications were a peculiar pulsating noise on the alternator and the readings on the phase ammeter and power-factor indicator. I should be glad of some additional information on this matter. The author is rather pessimistic about the extinguishing of fires. Recently, the stator of a 7 500-kVA alternator broke down and fired, with remarkably little resultant damage. The stator has now been rewound and is in perfect order, although the trouble occurred at the end of the slots where the winding is overhung. The machine was fitted with Merz-Price balanced protective gear, and this failed to operate. The gear was not to blame, however, as the system was not earthed. The Merz-Price gear is very satisfactory with an earthed neutral. Personally, I think that the author is inclined to put too much onus on automatic relays. He even suggests their use for dampers, fire extinguishers and other gear, etc., and rather ignores the personal factor. The author suggests the injection of steam in connection with fire extinction, but I have had no experience of this method. I have often wondered, however, whether it would not be possible to inject a gas, e.g. carbon dioxide, into the alternator end-bells to limit combustion of the windings.

Mr. L. Andrews: Dr. Smith's remarks remind me of the criticisms made upon a paper * which I read before the Institution in 1898 upon protective devices for alternating-current generators, to the effect that with properly designed generators such devices were unnecessary. It is a healthy sign to have a paper dealing with improvements in both generators and protective devices, since it is an indication that generator builders and switchgear makers are working together to deal with the matter as a common engineering problem.

Mr. E. T. Williams: I agree with Mr. Andrews that switchgear designers and dynamo designers should work together. I find, however, that electrical engineers, particularly designers, when they come up against a problem which tempts them, evolve most ingenious devices and yet lose a sense of perspective of the whole problem. During the past 25 years I have seen device after device installed in power stations and then put out of operation entirely because it was found that the troubles due to such devices were far greater than those which they had been installed to prevent. Too rarely do designers look at matters from the operator's standpoint. I maintain, and have maintained for a long time, that we should aim at greater simplicity, and I feel with Dr. Smith that if only we can get designers to give their attention to this question of reliability on the machine itself instead of giving it to protective devices, we shall be on the right lines. I am certain, from the vast number of protective gear that I have seen discarded, that one must maintain a very critical attitude indeed before advocating anything of this kind to protect the alternator.

Mr. S. Neville (*communicated*): In the author's method of deducing the discharge curves from the open-circuit magnetization curve of the machine it is necessary to obtain the slope of the magnetization

* *Journal I.E.E.*, 1898, vol. 27, p. 487.

curve for each value of the current, and then to construct the time/current curve by drawing a number of subtangents. The former process of differentiating is one which cannot be carried out accurately in practice, especially when the curvature is small (as it is for the lower part of the magnetization curve). Also it will be noticed that all errors due to using a small number of subtangents are in the same direction and are cumulative, although the second part of the process is fairly

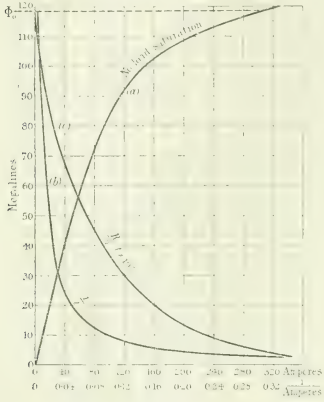

FIG. A.

accurate if drawn very carefully. No instrumental aid is available in either part of the work; and it is necessary to construct the curve from the beginning in order to find any particular point. The writer submits an alternative graphical method in which every stage is perfectly definite, and which, with the use of a planimeter, yields an accurate result in a minimum of time. The practical errors are not cumulative; and it is not necessary to construct the complete curve if only a point or a limited part of the curve is required.

The fundamental equation of discharge of an inductive circuit is :—

$$iR = -n\frac{d\phi}{dt}10^{-8} \quad . \quad . \quad . \quad . \quad (1)$$

where n is the effective number of turns,
R is the effective resistance of damping circuits,
ϕ is the instantaneous flux at time t,
i is the instantaneous current at time t.

Also, ϕ is a known function of i represented by the magnetization curve.

This equation may be written :—

$$\frac{R}{n}10^{8} = -\frac{1}{i}\frac{d\phi}{di} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Integrating (2) with respect to time, from the commencement of discharge (flux $= \phi_0$), we have :—

$$\frac{R}{n}t \cdot 10^{8} = \int_{\phi_0}^{\phi}\frac{1}{i}d\phi \quad . \quad . \quad . \quad . \quad . \quad (3)$$

To obtain the discharge curve (referring to Fig. A), plot $1/i$ from the magnetization curve (a), as a function of ϕ; and measure with a planimeter the area between the flux axis and the reciprocal curve (b), from the initial flux ϕ_0 to any required point during discharge. This area is equal to $(R/n)\ 10^8 t$, in which the value of the factor R/n is known, or must be assumed upon the principles discussed in the paper. Then taking any value of the flux (vertical ordinate), the horizontal ordinate of the integral curve (c) represents the time elapsed, while the horizontal ordinate of the magnetization curve (a) gives the corresponding current. The current plotted against time gives the discharge curve, as in Fig. B.

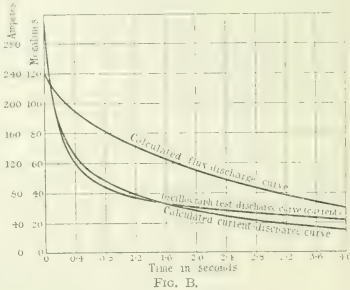

FIG. B.

Mr. J. Shepherd (*communicated*) : The author has provided an interesting and candid paper on the faults inherent in turbo-alternators as at present constructed. From the designer's standpoint, when the user of these machines stated the difficulties in somewhat the same manner, it was then said that the difficulties described did not exist, at any rate in 1920 (see *Journal I.E.E.*, 1920, vol. 58, p. 145). However, the author, who is constantly engaged in designing turbo-alternators, has the courage to make certain admissions in " Conclusions " Nos. (1), (2), (11) and (12) on page 776. As far as I am aware he is one of the first designers to advocate water-cooling as an advantage in modern generators, although it would appear that the risks from water leakage from coolers adjacent to the generator are as great as if the coolers were contained within the machine. If water-cooling be necessary at all, the design of the machine should be studied from the point of view of combining coolers with other possible advantages; otherwise the machine as at present constructed must possess the same faults whether cooled by external water coolers or not. So long as the mechanically weak stator bars are unsupported for a considerable

portion of their length, so must the risks of breakdowns, set out in conclusion (1) of the paper, be expected. If, however, the logical method of applying the water coolers directly to the source of heat within the machine be considered, the coolers can then be shaped to give adequate and complete support throughout the entire length of the stator windings. If these be carefully and continuously supported there is no reason to suppose that the life of mica insulation would not then be indefinitely prolonged; all the evidence we possess certainly points that way, in which case the elaborate and costly safeguards set out in conclusion (12) become unnecessary. If water-cooling be considered an admissible method of cooling turbo-alternators, the tubular form as shown in Fig. 1 is certainly not the safest from the leakage point of view. By the use of electric welding and electrolytic deposition much stouter forms of coolers combined with coil supports can be constructed. These views were set out at some length in 1920, and nothing has occurred since to shake their soundness: on the contrary, the proposals in the present paper may be considered a half-way approach thereto. As the size of single generators and of the systems to which they are connected increases, the half-way approach will probably end in complete agreement. The size of future problems will decide.

we have had during the past four or five years only one failure due to an external short-circuit, in which case the protective gear acted promptly and the damage was only slight. We have, however, still to contend with occasional failures of insulation, and modern methods have reduced these also to a minimum, which will be confirmed by a record of breakdowns on generators given by Mr. Juhlin in Volume 59 of the *Journal* (page 300). As regards the importance of mechanical details, the purely electrical calculation is only a small part in the design of turbo-alternators. The problems arising in connection with the design of the large high-speed units which are at present available, have been largely of a mechanical nature. Dr. Smith agrees that it is as well to break the field rapidly when a fault occurs in the machine; this is what the paper advocates. The main field breaker comes into action only in the case of a fault. Dr. Smith mentions that the flux and the stator voltage may persist for perhaps a minute; this is not the case. Theoretically, the flux persists of course indefinitely, decreasing continually. The time required for the flux to disappear to a small value can be ascertained from the slip-ring

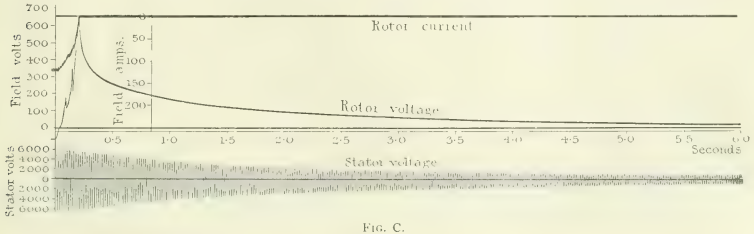

FIG. C.

Mr. J. A. Kuyser (*in reply*): The President is evidently in agreement with the remarks made in the introduction to the paper, namely, that the cost of generator protective gear is small compared with its value as an insurance against serious loss. Compared with the large amount of capital expended to protect distribution systems and power-consuming apparatus, the cost of protecting the generating plant itself is comparatively insignificant.

It is perhaps unnecessary to state that I entirely agree with Dr. Smith's view that generators should be designed so that they will withstand a short-circuit, and I would confirm again the statement made in the paper, that difficulties due to short-circuits are practically overcome by the modern methods of bracing the winding. The company with which I am connected, and its associated American company, have, I believe, been foremost in advocating the policy that turbo-alternators should be tested on a dead short-circuit in order to discover and remedy weak spots in each type of winding. As a result, voltage, which is proportional to the rate of change of the disappearing flux. When the slip-ring voltage is reduced to zero, the only flux that remains is that due to remanence. In Fig. 14 of the paper, taken on a plate rotor, the time required is less than 2 seconds. For a solid rotor, Figs. C and D illustrate the condition for a 25 000-kVA, 1 500-r.p.m. machine, for a direct open circuit, and for the case of a 1:1 discharge resistance. Stator voltage, slip-ring voltage, and field current are recorded. It will be seen that the stator voltage and slip-ring voltage disappear together, although not proportionally. In the case of the direct open circuit approximately 6 seconds are required for the stator voltage to reach 10 per cent of the normal voltage. The oscillograms given in the paper are taken under no-load conditions, except that shown in Fig. 3, which was taken during a dead short-circuit at the terminals, the protective relays opening the main breaker and the field circuit. It will be seen that in this case the fault currents are reduced to a negligible value in less than 1 second, due to the demagnetizing action of the fault currents themselves, which assist in reducing the flux more rapidly. The rapidity of operation of the protective gear is therefore increased with the severity of the fault.

Major Edgcumbe agrees with the recommendation to

break the field directly by the relays, instead of indirectly by means of an auxiliary switch on the main breaker. Several other speakers in the Manchester, Newcastle and Leeds discussions gave evidence of the small disturbance caused by a machine temporarily losing its field. As regards the direction of the current when operating without field, we should distinguish between watt current and wattless current. As is stated in the paper, the machine operates as an induction generator, increasing its speed, and continues supplying watt load in the same direction as before. The wattless current component is, however, reversed as the machine is magnetized by wattless current drawn from the system, as in an ordinary induction generator. Reverse-power relays are operated by the watt component, and it is therefore useless, as is stated in the paper, to install these relays for the purpose of disconnecting the machine from the mains in case the excitation fails. As regards the rapidity of the discharge, this has been dealt with in my reply to Dr. Smith. It is clearly stated in the paper that after the disappearance of the current, the flux and therefore the stator voltage still remain. The process

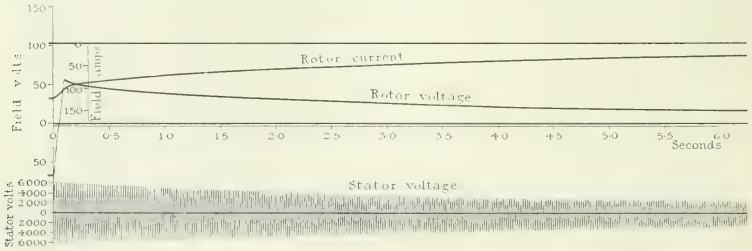

FIG. D.

of the discharge is therefore only beginning when the field current has been interrupted. The reverse-power relays shown in the diagram are provided for the purpose of stopping the set in case of mechanical failure of the prime mover, and two relays are sufficient for this purpose. It is doubtful whether reverse-power relays will give protection for faults which are not dealt with by the Merz-Price relays, and for this reason the third relay is omitted.

I am pleased to note that Mr. Clothier is generally in agreement with the proposals contained in the paper. The question of the size of the earthing resistance is very important. Unfortunately, however, opinion on this subject varies considerably, and practice is not uniform or consistent. In some modern power stations the generators are earthed solid; in other large stations the current is limited to approximately 50 per cent of the normal current per unit. In many cases, as Mr. Clothier mentions, cost considerations determine the size, and this is a mistake, in view of the small capital invested. In other cases space limits the size of resistance. If economy in space and cost is desired, it would probably be better to reduce the time specified for carrying the main current, rather than use a high ohmic value; a period of approximately 30 seconds would probably be ample in most cases. As regards the ohmic value of the resistance, the advantage of large tripping currents is that a larger part of the winding is protected; the disadvantage is that the burning is increased. As a compromise, I would recommend for the present a resistance passing 100 per cent current if Merz-Price gear with 15 per cent relay setting is used, which will give protection to 85 per cent of the winding. If a specially sensitive earth leakage relay is used, set at $7\frac{1}{2}$ per cent, the resistance can be designed for 50 per cent current. If self-balancing gear is used, the relays being set at 20 amperes, the resistance should pass 200 amperes, and this will give protection to 90 per cent of the winding. I think that it would be preferable to allow rather large tripping currents, in order to make certain of the operation of the gear, although the severity of the fault is thereby increased.

Mr. Sloan agrees that accidents will happen, and that design is not yet perfect. To this a statement should be added, that the workmanship and operating conditions are not always perfect. The best-designed machine may fail if subjected to abuse, or faults in manufacture may be responsible for failure. As regards the quickness of operation of the mid-point gear, a fault between turns will mostly be due to a metal-to-metal contact, or will develop quickly into such, before the winding will become ignited and go to earth, and the relays should trip instantly. Tests with a magnetic series blow-out have been made. The time for the current to be interrupted is, however, only slightly reduced, and the pressure-rise is approximately the same as with an ordinary circuit breaker. If a shunt blow-out is used having a constant magnetic field some gain may be made, and tests are contemplated to confirm this. As regards steam versus water, I would expect steam to introduce less condensed water into the rotor and stator, and be preferable on this account.

Replying to Mr. Brazil's point regarding the number of leads on the mid-point gear, this should not be a grave objection, as the wiring for existing protective gear contains already a large number of leads and the extra mid-point leads do not constitute a large percentage increase. The potential leads should be made of sub-

stantial section to be mechanically sound; there is not much objection to making the three mid-point leads of the same section as the main generator leads. As regards the size of the earthing resistance, this is dealt with in my reply to Mr. Clothier. In the case of the mid-point gear, the resistance can be made small if highly sensitive relays are used. Actual figures will have to be obtained by experiment.

In reply to Mr. Jockel, the extra expense on the generator if mid-point gear is used is negligible. As regards the sensitivity of the gear, tests were made on a turbo-alternator and showed that the mid-point gear will operate with certainty in case a single turn is short-circuited. As regards the personal element, it is generally considered that this cannot be counted on in case of a serious accident, quite apart from the delays which are avoided by automatic operation.

I agree with Mr. Andrews that the subject of generator protective gear should be considered jointly by the generator designer and the switchgear designer, and this in the past has not been sufficiently realized.

Mr. Williams's opinion of electrical engineers, particularly designers, it will be generally admitted is rather harsh. Designers nowadays are keeping generally in touch with operating conditions, and I can assure Mr. Williams, as well as Dr. Smith, that reliability has always been one of the first considerations in the design of turbo-alternators; and records of turbo breakdowns due to faulty design have been very satisfactory indeed, considering the design problems which had to be faced.

Mr. Neville's method of determining the discharge curve is an improvement on the subtangent method proposed in the paper, and it is to be recommended where very high accuracy is desired.

In reply to Mr. Shepherd's remarks on water cooling, I do not advocate, at least at the present time, water cooling for turbo-alternators, and I would refer to my remarks on Mr. Shepherd's paper;* the main difficulty with fluid cooling is the heat-drop through the insulation, which is not reduced by fluid cooling, but rather increased owing to more insulation thickness being required. A real benefit could be obtained by bringing oil in direct contact with the copper conductors. The difficulties in such a construction appear, however, to be too serious for this method to be considered any further at present. It is possible to design with air cooling the largest high-speed generators for which turbines can be built. A 20 700-kVA, 3 000-r.p.m. machine is under construction, and this does not represent the limit.

* *Journal I.E.E.*, 1920, vol. 58, p. 270.

North Midland Centre, at Leeds, 28 March, 1922.

Mr. R. D. Spurr: In Bradford all the alternators are protected by the Merz-Price current-balance system shown in Fig. 2. After two stators in which the field was not opened quickly, owing to the machines being separately excited from the main d.c. busbars, had been burnt out, we added automatic field switches so connected that in the event of the main oil switch opening through the operation of the protective gear the field is opened at the same time. One point in favour of the current-balance protection is that unless the protective gear is sound the alternator cannot be run. It acts as a protection against any defects in the current transformers, fuse box, resistances and wiring; this characteristic is seldom mentioned but is very much appreciated by those who use it. It is interesting to know that we could dispense with the field-breaking resistance with modern solid rotors. I am of the opinion that the mid-point protective gear shown in Fig. 5 is complicated by the addition of tappings to the middle point of each phase of the stator winding. Fire prevention rather than fire extinguishing should be considered. The author mentions that, even though air filters are used, a considerable quantity of dirt is deposited on the stator windings. This dirt can become electrically charged and the static discharge will soon bring about a total failure of the insulation. A good plan would be to remove regularly the end shields and rotor, and spray or paint the whole of the windings with good varnish in order to keep a smooth surface. If steam jets could be turned on simultaneously with the tripping of the oil switch the result would be effective, but not otherwise. Air dampers in the inlet and outlet ducts, closed by some interlocked control gear operated by the protective gear, would probably do much to prevent the rapid spread of fire.

Mr. A. F. Carter: There is one point on which I should like to bear the author out. Some years ago I witnessed the opening of the field of a 1 500-kW, 25-period, 160-r.p.m. Westinghouse alternator running in parallel with two 10 000-kW machines and 7 smaller machines. Rather to our surprise nothing happened, the field switch again closing after perhaps 15 or 20 seconds. Another rather curious accident occurred at the same place. We had probably 10 000 kW of 25-period plant running, and about 8 000 kW of direct-current plant, the machines being tied to the busbars without any trips, with the exception of alleged failing-field trips on the alternators and reverse trips on the d.c. machines. Owing to a mistake in switching, the excitation was cut off at the exciter which excited all the alternators in parallel. The d.c. bars and the a.c. bars were to a certain extent in parallel through about 3 000 kW of rotary converters and motor-generators, some of which were 3 miles from the power house. This failure of the field—I think the voltage dropped to about 10 per cent—resulted in almost a short-circuit. The d.c. generators pumped a heavy current via the rotary converters into the a.c. machine. From the moment of the fault occurring to the time when normal conditions were again reached only 9 minutes elapsed. No damage resulted, but the alternators came out of parallel. Can the author say why, when a failure of field occurs and the oil switch remains in, the current does not rise to enormous values?

[The author's reply to this discussion will be published later.]

North-Western Centre, at Manchester, 4 April, 1922.

Mr. G. A. Cheetham: I wish to confine my remarks principally to the protective schemes mentioned in the paper. The Merz-Price system undoubtedly has some disadvantages, but it has certainly proved its efficacy in service. Of course the setting of the gear depends upon the value of the earthing resistance, and I think that the settings mentioned on page 764 assume that the earthing resistance is of such a value that with a dead earth on one phase full-load current flows. The figure of 100 per cent full-load current for the setting of the relays undoubtedly refers to some very old equipment. It is possible now to give a setting of 15 per cent of full-load current quite easily without any danger of the gear tripping under overload conditions. The trouble when 100 per cent settings had to be given on relays was due to the fact that designers had not recognized that current transformers could not be readily balanced when the transformers were working on a very low portion of the magnetization curve, and the remedy was provided by increasing the impedance of the relay circuits, so that the transformers worked higher up on the magnetization curve. When this was recognized the trouble disappeared, and Merz-Price gear does function extremely well nowadays. On several occasions I have seen Merz-Price gear operating when the difficulty of the engineer has been to find a fault, and when he has found it it has not been a very expensive matter to repair it. Referring to the self-balancing gear, it will be noticed that the principal difference between that and the Merz-Price gear is that it gives a definite current setting and not a percentage of the full-load current. This is because the transformers in this gear, under fault conditions, are simply bar-primary transformers, and the lowest fault current which will operate the relays is the minimum current which will flow through a bar-primary transformer to provide sufficient voltage to overcome the impedance of the relays. It follows, therefore, since this is a fixed current, that when the full-load current of a machine is low it is possible to obtain Merz-Price gear which will give a better protection than self-balancing gear. Under normal conditions I agree that self-balancing gives a lower fault setting than the Merz-Price gear, but within the last year or so there has been introduced an improved scheme in connection with the latter apparatus, which consists in two relays connected as phase relays having a comparatively high fault setting, which are susceptible to faults between phases only, and one other relay of low setting which is susceptible to earth faults only. This scheme has enabled designers to give Merz-Price gear protection at $7\frac{1}{2}$ instead of 15 per cent with an earthing resistance passing full-load current with a dead earth on one phase. Again, with self-balancing gear it is necessary to be careful when there is a joint in the iron circuit of the protective transformer, as regards the position of the leads. The joint is, of course, a convenience as it enables the transformer to be built round the cable, but on the whole it is better to avoid the joint. The author refers to certain minor disadvantages of the self-balancing gear. One of the principal disadvantages is that the neutral connections have to be brought up by cable to the switchgear cubicle if protection of the whole of the cable is to be obtained. That, certainly, is expensive. It is usual in such cases to fix a sheathed cable, or similar arrangement, and put the balancing transformers at the machine terminals and not in the switchgear cubicle. With regard to the new mid-point protective gear, it is true that additional protection is given—i.e. protection between turns—but it has two disadvantages. One is the utilization of potential transformers. Generally the tendency is to leave out potential transformers for protective purposes wherever possible. The other is that in this system the generator terminals themselves are not protected.

Mr. H. C. Lamb: The paper illustrates the difference between the point of view of the designer and that of the power engineer. The designer is preoccupied with making his design as perfect as possible and, when that is done, with introducing automatic devices which will prevent the complete destruction of the machine should a fault occur; but the power engineer has an equally important consideration, i.e. the maintenance of the continuity of supply. If there is one thing which he abhors more than another, it is that there should be any interruption through the operation of some automatic gear for no proper cause. It is for this reason that he likes to have the two links in connection with the automatic cutting out of the generator field to which the author refers—not because he imagines that any harm will come to the generator if the field is cut off. I had an experience which confirms exactly the author's statement. Two 6 000-kW generators were running in parallel on night load and the field was accidentally switched off one of them. Nothing happened except that the busbar volts fell, and the machine dropped some of its load through the action of the governor. But the author has given us good reason to consider whether we should not attempt to speed up the cutting off of the generator field by having only the one operation of the main relay. In one case of a 20 000-kW generator the double operation acted perfectly. A short-circuit occurred right across the main terminals. The out-of-balance Merz-Price gear operated, and the field current was cut off when the main switch opened. The damage done was very slight indeed, being confined to the main terminals. One is reluctant, for the same reason, to make air dampers on the generators automatic. It is considered that there are advantages in having them operated by hand, provided that easy means are available for tripping them in case of need. I do not know any power engineer who would contemplate making an automatic steam connection to his generators. A steam connection may be an excellent thing, but very adequate precautions would be necessary to ensure that it did not cause the breakdown of the generator. In giving his list of causes of damage to high-tension windings the author has, I think, omitted one, i.e. mechanical faults on rotors. Cases have been known where a mechanical breakdown of the rotor has been followed by the destruction of the stator windings. I quite

agree with the author as to the advantages of the closed air system. In Manchester we have a machine running quite successfully with that method of cooling. But there is a difficulty in stations which are not situated on a riverside, in that the necessary quantity of cold water is not available, supposing that all the machines are equipped with the closed system, because in summer the temperature of the cooling-tower pond is too high for generator air cooling. There is one precaution I might mention in connection with the closed air system, namely, that the pressure of the water inside the cooler should be below the pressure of the atmosphere. If this is not the case one is only adding to one's anxieties, because, at some time, a leak is sure to occur and might be the cause of breakdown. If the pressure of the water in the cooler is below atmospheric pressure this danger is absent. The author's new system of mid-point protection no doubt has something to recommend it, but I feel that it comes too late. At one time many would have welcomed it because it would operate the out-of-balance relay in case of a fault between turns. But to-day there should not be any faults between turns. In the old days, when we had cotton insulation and 8 or 9 turns per slot, faults did occur between turns, but now that there are only 1 or 2 turns per slot, and mica insulation, they should not occur. The author says that we still get faults between turns because of the difficulty of insulating the end winding. One can see no reason why there should be this difficulty. Having a voltage of only 100 or 120 between turns with which to contend one would think that, given a good design and—what is equally important—good workmanship, there should be no danger of these faults between the turns of the end windings. I was recently looking over a record of some 50 breakdowns (most of them having happened a good many years ago) and I did not see one case where the fault occurred through a breakdown between the turns of the end windings. In nearly every case the fault began inside the slot. In the old days of open-type machines it would not have been regarded as necessary to get a machine isolated immediately because of a burn-out of a single coil, and in many cases a generator has run through and carried its load, after a fault has occurred, and the winding has been burnt through without going to earth. At one time, when there was a shortage of plant, a strap was kept in the station ready to short-circuit a burnt-out coil, the generator subsequently being put on load again, if there was not time to make a repair. With an enclosed type of generator, of course, it is essential that if a fault occurs it should be isolated as quickly as possible. In one case a fault between turns began inside the slot and a minute or two elapsed before the generator was isolated; and in that time the fault developed to a short-circuit between phases, the winding was wrecked and the core badly damaged. One objection to the author's mid-point protection system has been mentioned by Mr. Cheetham, i.e. the use of potential transformers. It appears to me, from Fig. 6, that a breakdown of the winding of one of the transformers or the blowing of one of the protective fuses of the transformer would cause the relay to operate and cut the generator out. I do not think any power engineer would contemplate installing the system shown in Fig. 8, where two generators would be cut out in the case of a fault on one. After giving a very complete list of the protective gear necessary the author concludes by saying: "It is questionable whether the complete protective system outlined above is necessary, as a fire can usually be prevented if the main field is 'killed' instantaneously." That, I think, is the object for which we should all aim.

Mr. G. A. Juhlin: I think that the foremost object of a manufacturer is to produce machines which will not break down in service, and so prevent the interruption of supply. Statistics show that the percentage of breakdowns is decreasing, so that it may truly be said that we are gradually approaching the ideal state of having no breakdowns. Troubles due to short-circuits have been practically eliminated, but it should be realized that there are causes of breakdowns over which the manufacturer has no control, and for this reason it would be taking unjustifiable risks to run plants, the cost of which amounts to tens of thousands of pounds, without taking every available step to minimize damage resulting from a breakdown which may take place. There is no doubt that if the present-day protective devices had been available in the early days of turbo-generator plants, a great deal of money would have been saved, because very small faults frequently caused complete burn-outs due to fire when machines were operated without protective gear. The author gives several causes of insulation failure. A great deal of trouble has been caused by dampness. It may be of interest to mention a case where a machine broke down at half voltage on starting up after having been standing for about 4 days. The cause was found to be sweating due to the fact that the air outlet of the machine was taken outside the power house. Sudden temperature variations had been experienced during the time the machine had been shut down, with the result that moisture was deposited on the windings to such an extent that they were practically saturated and the insulation failed. The use of properly placed dampers would obviate such cases of breakdown. Dampers are frequently considered an unnecessary complication, but there is no doubt that they have a proper place in a complete system of protection. Great progress has been made in the way of insulation for large machinery, both as regards quality of material and the method of application. The use of mica has been extended to the end windings, with highly satisfactory results. Previous to the adoption of mica tape for the end windings, troubles were experienced due to mechanical damage of the empire tape then used. Since the adoption of mica tape, considerable improvements in insulation failures have been obtained. Last year the number of insulation breakdowns of turbo plant manufactured by the company with which I am associated, was $1\frac{1}{8}$ per cent of the plant in operation, which I think is an excellent result. The author has referred to the use of string for holding stator windings in position. I entirely agree with him that this is most undesirable, and not in accordance with best practice. By employing proper mechanical clamping, it is possible to produce machines which will withstand short-circuits at the terminals. Tests are frequently made to demonstrate this, and actual operating experience has shown machines

to be perfectly safe in this respect. The most valuable part of the paper, in my opinion, is that dealing with the automatic field switch. The author has set forth very clearly the relative value of the different schemes in use, and the whole position is summarized on page 775. Actual experience has shown that the breaking of the alternator field is the most satisfactory method for "killing" the field in the event of a fault in the stator winding. We have had two instances of large machines which were saved from serious damage by the Merz-Price gear, and automatic field protection. In each case water, caused by the freezing of the wet-air filters, was drawn into the machines. These cases emphasize the fact that short-circuits are not the only source of danger and that breakdowns are liable to occur, no matter how well the machines are constructed. It would therefore be unwise to adopt the policy of no protective gear on the score that machines should be built so that they do not break down. The author mentions external reactances as a means of protecting generators. I think this is a question which should receive careful consideration, because better protection is obtainable by using external reactance than if the reactance is embodied in the machine itself. Very high internal reactance is apt to lead to freak designs which do not offer any advantage.

Mr. H. A. Ratcliff: There are on the market many forms of electrical protective gear for generators. Most of them are of the balanced or differential type, and the number of possible combinations of the essential parts of the gear appears to be illimitable. The simplest method shown in the paper is probably the Merz-Beard self-balancing arrangement, but, unfortunately, in the case of a large generator it is not always an easy matter to fix the current transformers on the conductors, and where there are several cables to be taken through each one the transformers become unwieldy in size. That may account for one fact which I cannot quite reconcile with the statement made in the paper. The author says that the minimum operating current is of the order of 20 amperes, but from experience I should say it was more likely to be about 200 amperes. The author's reference to the effect of loss of field upon balanced protective gear and reverse-power relays is very interesting, as quite recently I heard it claimed that a particular form of balanced gear afforded protection against loss of field, whereas actually it did nothing of the sort. In the case of reverse-power relays the conditions are rather different, since they may or may not operate; usually they do not operate, and, furthermore, it is usual for them to operate when they should not operate. The mid-point protective gear described in the paper covers a rather more extensive range of faults than the ordinary differential forms, but I have not yet heard of it having been tried out in practice, and I should therefore like to know whether the author has had any extended experience of its behaviour under actual operating conditions. The potential transformers are undoubtedly the great weakness of the system and are quite sufficient to condemn it, in my opinion. There is another possible method of protection in the case of a machine having duplicate windings, as shown in Fig. 7. Instead of the two mid-point tappings with the trip coil bridged across them, the two ends of the parallel windings are taken through separate current transformers or in opposite directions through a single ring-type current transformer, and so give a differential balance in the same way as the well-known Merz-Hunter system for the protection of cables. It is obvious from the information given in the paper that the function of most of these protective devices is to save time, since every second is of consequence when it is a matter of preventing the complete "burn out" of a generator. The idea is, of course, that the automatic apparatus will short-circuit the human element and so eliminate the time-lag inseparable from the latter. That is to say, the gear must be absolutely above suspicion and perfectly reliable, or, in other words, it must be more reliable than the human element, and further, it must be more reliable than the plant which it has to protect. I do not know what the author's opinion is on that aspect of the matter, but my experience is that as a rule protective gear requires quite as much protection as the plant which it is installed to protect. At the foot of col. 1, page 773, the author says: "If all apparatus belonging to the protective system could be absolutely depended upon," and this rather supports my view. The most interesting portion of the paper is that dealing with the rupturing of the field, and in that connection it is rather startling to find that on the subject of the self-inductive coefficient most of the textbooks are wrong. I should like to suggest that the apparent error may be due in some cases to the interpretation of the information given in the textbooks, as I find that in most of the standard works there is generally some qualifying reference to the permeability of the magnetic circuit. However, the matter is not of much consequence in so far as it affects the author's deductions, since he arrives at the ultimate result that the pressure variation on rupturing the field is proportional to the change in the resistance of the circuit. The ordinary formula for the decrease of the current in an inductive circuit leads to the same result. When considering the subject of field suppression some two or three years ago it occurred to me that by shrouding the rotor windings in some way the effect would be the same as that produced by the damper bars or windings on a salient-pole machine, and consequently the mutually inductive action would tend to reduce the pressure-rise in the field circuit. The scheme did not, however, appear to be very practicable, and although at the time I anticipated that in the case of a solid rotor there would be some mutual inductive action, I did not expect that the effect would be so marked as the author shows it to be. Although the effect of the currents induced in the rotor iron is apparently sufficient to enable a discharge resistance to be dispensed with, there is no reduction in the time required for the suppression of the field flux unless obtained at the expense of an increased pressure-rise at the field terminals. Whether the discharge resistance is in the field circuit or in a mutually inductive circuit is therefore immaterial, but in either case its value must be relatively high if the field is to be suppressed quickly. Unfortunately, the resistance of the rotor iron path may be more or less of a variable quantity, and in any case its effects can be ascertained only by experiment, whereas the

advantage of a discharge resistance in the field circuit as that its value may be adjusted to give any desired value of pressure-rise and rate of field suppression. In this connection the advantage of winding the field circuit for a comparatively low excitation pressure will be obvious. I quite agree with Mr. Lamb that the elaboration of these various protective schemes may be overdone, and may reach a point where the continuity of supply is imperilled. Incidentally, I should like to ask the author what would happen in the case of a large generator on full load if the air-duct dampers were inadvertently operated, and the generator continued to run unobserved on full load.

Mr. S. Ferguson: The paper deals with faults which may be developed in the generator, but it appears to pay no attention to the effect of external faults on a generator. It seems to me that a fair proportion of breakdowns in generators occurs through surges on the cable system, which are quite harmless as such, but on entering the windings of the generator, due to the change in natural impedance causing a high voltage-rise, they break down the insulation of the end turns. I should like to ask the author if he does not think that external reactance will form a wall of protection for the generator against the entry of these surges into the windings. I think the reactance would protect the windings of the machine in such cases. With regard to the schemes of protective gear for generators there is no doubt that the Merz-Price balanced circulating-current system has proved a great benefit. A simple form of protective gear which has not been referred to by the author is the Ferranti-Field system, which consists of a core-balanced transformer slipped over the lead covering of the cable. The neutral of the machine is passed through the hole in the transformer, so as to prevent it operating due to earths external to the protected generator. The scheme is exceedingly simple and will operate with leakage currents of from 10 to 30 amperes. It does not protect against short-circuits between phases which do not go to earth, but it is hardly conceivable that such short-circuits would exist long without going to earth. Only one fault-current transformer and one single-pole relay is necessary, as against three with the Merz-Price system. There are only two pilot wires and there is an entire absence of high-tension apparatus. The transformer is merely slipped over the lead covering of the cable so that there is no danger introduced by the protective transformers themselves. One very great advantage of this gear is that there is no possibility of accidental operation due to the unbalancing of the current transformer on short-circuit conditions exterior to the machine, and there is no danger of accidental operation due to short-circuit on the pilots. There has, I think, been a tendency for machine builders to call for neutral earthing resistances to pass heavy currents, say up to the normal current of the machine. I do not know whether the shock to the system, due to every earth which comes on passing the normal full-load current, has been fully appreciated. With 10 000-kW machines the disturbance due to the fault power would be very much greater, and I think that means should be provided whereby the limiting resistance does not pass anything like full-load current. It certainly points to the fact that a limiting resistance with negative temperature coefficient, which passes a limited current at starting and gradually increases due to the heat developed, is an advantage. I think there is great need for simplicity in protective gear. I know quite well that sometimes there is a link in the protective gear which fails to operate at the correct time. Personally I am very desirous of eliminating all relays and operating directly with the fault current. In many cases this can be done by a mechanical power-reduction mechanism in connection with the oil switch, so that ordinary fault currents are capable of operating the automatic release coil with small settings. With a relay system there are so many links in the chain to go wrong, e.g. a relay coil, and relay contacts—flimsy metal contacts which sometimes make circuits and sometimes do not. Then, again, an independent source of supply has to be relied upon, and this may fail. Another link in the chain is that the oil switch has to be provided with an auxiliary contact to cut off the supply from the release coil when the oil switch opens. In this case again there are flimsy contacts. The failure of any one of these 5 or 6 links in the chain renders the protective apparatus useless. It is possible that in the future many of these relays will be cut out and the oil switch will be automatically operated directly with the fault current on the release coil, the necessary power reduction being effected by a mechanical arrangement in the switch mechanism. This new scheme of protective gear appears to me to be rather too complicated to be of value, especially seeing that it is difficult to conceive a fault between turns which does not get to earth. I should like the author to say what sensitivity he hopes to get by this arrangement. He refers to the centre point of the winding going to earth. With the fault in that position I think he will get a maximum fault-operating current, but this current will gradually decrease as the outer ends of the phases are reached, and I believe that a short-circuit at the machine terminals would not operate the gear, which certainly seems to put it out of court. I do not think that the amount of current likely to be obtained with this arrangement from the ordinary potential transformers suggested, would be nearly large enough for the duty. If the pressure between turns is, say, $2\frac{1}{2}$ per cent of the normal pressure, and a standard 200 volt-ampere potential transformer is used, it seems to me that the power available for tripping purposes will be $2\frac{1}{2}$ watts, which is not a large amount of power to energize the current transformer, relay and the pilot leads where the protection of a large machine is concerned. I feel that if the scheme is to be of any value a reactance passing a larger current than the primary of the potential transformer would be necessary. I should like to ask the author if he has considered utilizing one reactance of large carrying capacity connected across the busbars to which mid-points of the machine could be connected. It seems to me that rather than have a potential transformer for each machine it would be practicable to have one large reactance on the busbars.

Mr. J. Frith: Nearly all the speakers have mentioned, in effect, that nine-tenths of the trouble is caused by failures of potential and current transformers. Why

cannot they be more like engineering devices rather than merely instruments? They have charge of so many thousands of pounds worth of machinery that it seems a great pity to try to save a few shillings by making them so flimsy. It seems that it is now necessary to specify when asking for a turbo-alternator that it must be safe to open the field without any breaking resistance. Can the author say whether, in the closed system of air cooling, it is customary to eliminate the oxygen from the air?

Mr. R. Townend: The author gives 30 seconds as the time required for the field current to die down to 10 per cent of its normal value in the case of a large 2-pole, 25-period machine. It would be interesting to know how long it would take to establish a fire in the end windings of such a machine, and it should be noted that with an excitation considerably lower than 10 per cent of normal, the stator voltage may be sufficiently high to maintain an arc. Perhaps the quickest way of "killing" the a.c. voltage would be to short-circuit the stator terminals as soon as the field switch opened; if considered necessary, a very small time-lag could be introduced in order to eliminate any risk of distortion of the stator windings due to short-circuit. It should, of course, be remembered that if an internal short-circuit occurs, this in itself will help to kill the a.c. voltage, but it is possible for a short-circuit between adjacent turns to cause dangerous burning without having a big demagnetizing effect on the field. With reference to faults between turns in the stator windings, it should be remembered that, although the normal voltage between turns may be comparatively small, the instantaneous voltage between turns adjacent to the terminals may be very greatly increased in the case of an external short-circuit. This is well understood in the case of induction motors, but is liable to be neglected in the case of synchronous machines. The author refers to fitting the exciter with a compound winding, and I certainly agree that this is desirable. About 11 years ago I experienced trouble with a large 2-pole alternator fitted with a shunt exciter; when the machine was taken off the bars, the field resistance was cut in circuit ready for the next start, and, unless this was done slowly, the reaction from the alternator field caused the exciter armature current to reverse the polarity of the exciter. A comparatively small series winding on the exciter prevented this from occurring.

Mr. E. P. Hill: The author mentions breakdowns caused by condensation on the windings and core, due to the windings having a lower temperature than the cooling air. A few years ago I came across a cause of trouble in enclosed sets which developed from a different source, but which is likely to prove as fatal to the stator insulation. The air was drawn from outside the power house through a wet filter, and during cold weather it entered the end bells at a temperature almost at freezing point. Due to escaping steam from sealing glands, etc., much water condensed on these cold surfaces and ran down to the bedplate whence it was drawn in on the suction side of the alternator fan through the small crevices and deposited on the windings. It is safer, therefore, to draw in the air from the room until the whole machine is at a sufficiently high temperature to prevent condensation. On several occasions I have had trouble due to oil depositing on the windings, which retains the dirt and gives a low insulation resistance; in certain cases this has actually got in from the revolving drum-filter bearings, due to the air suction, and ball bearings became necessary. In connection with the author's protective scheme for stator windings, if two faults developed at certain critical distances from the centre tapping of the winding, it would appear that the relay would not operate. I take it that this possibility is considered very unlikely. With regard to the breaking of the rotor field current by the circuit breaker, the actual breaking effect of the switch will be very important. If the breaker opens exceedingly quickly, with a big magnetic effect, then care must be taken to ensure that high voltages are not induced in the rotor. It is the practice in some stations periodically to test out the field-breaking switches. With the author's arrangement, dispensing with the discharge resistance, in certain cases of laminated rotors of older type, mechanical damage might occur from the passage of the damping currents when the field is broken, and repetition might eventually cause trouble. In connection with the spark-gap mentioned by the author as desirable in order to test with an old rotor whether the induced voltage on breaking full field current is excessive, it may be desirable to insert a limiting resistance in series with the gap to reduce oscillations should the gap actually break down during the test.

Mr. J. H. Buchanan: No one is more alive to the defects which have been discovered in potential and current transformers in the past than the maker; at the same time he has a certain difficulty in regard to supplying the apparatus which he thinks best. In my own experience I have found that in the majority of cases much more importance is attached to an increase in the cost than to anything else. But although breakdowns on such transformers are known to occur fairly frequently, I have found that the percentage of breakdowns to those in service is far below what has been given in the discussion as the percentage of breakdowns of generators, and amongst transformers of recent design the breakdowns are only a fraction of what they were a few years ago. The question of specifications has been mentioned. In that connection I should like to say that what is one man's meat is another man's poison. It is impossible for a manufacturer to supply the large variety of transformers that will meet every specification. The result is that he is, in a way, discouraged from spending a lot of money in developing designs which will appeal to comparatively few people; he endeavours to do the best he can at the minimum cost. As an example of this I should like to refer to the question of the balanced-current Merz-Price transformer. It is stated in the paper very prominently that two current transformers seldom have identical magnetic characteristics. While that is very true of a current transformer of ordinary design which is used for operating ammeters or watt-hour meters, it is not true that it is impossible to make transformers for the purpose which will balance very well on very heavy overload, say 10, 15, 20 or even more than 20 times full-load current. I believe it is quite possible to make

two transformers of reasonable design which will balance together when connected simply with a milliammeter on the secondary side with an out-of-balance current practically down to 9 milliamperes, with 10, 15, or more than 20 times full-load current, for a primary current of, say, 300 amperes. That is very much less than the out-of-balance current one would get with ordinary current transformers. Transformers like this have already been made for balanced-voltage protection, and I think it is equally possible to make them for balanced-current protection. With regard to the self-balancing arrangement, some remarks have been made about the out-of-balance current required for tripping. I think it has been made fairly clear that this cannot really be reckoned as a percentage. For a given transformer it is a definite primary current in amperes which will give a definite secondary tripping current. The paper mentions tripping currents down to 20 amperes. These have been obtained on rather small transformers and, in fact, tripping currents have been obtained even below that figure, but as an example of what a somewhat larger one will do I may give the following instance. The other day for a special purpose I was trying a ring-type transformer, which avoids the disadvantage of joints in the core, and without any difficulty I could get a relay set at 0·25 ampere to trip out with under 40 amperes out-of-balance current. That was a fairly large core with an internal diameter of $7\frac{1}{2}$ inches. Reverting to the question of what may be called the quality of transformers, it has been stated that potential transformers are much less dependable than current transformers. To some extent that is true. They have more turns and they certainly have caused more breakdowns than current transformers; but I should like to emphasize that, even in the past two or three years, we have improved the results enormously. We have reduced the percentage of breakdowns several times over. The author states that potential transformers can be provided with mid-point tappings and used for protective gear, and that they can also be used for operating watt-hour meters, etc. I think it is well worth remembering that the best results cannot always be obtained when transformers are used both for protective gear and for working instruments. The best results are generally obtained by keeping protective gear and measuring instruments quite separate.

Mr. D. S. Paxton (*communicated*): The author divides air-cleaning apparatus into dry filters and wet filters, but it may be pointed out that an intermediate class is now available. This is of comparatively recent introduction in this country, and possibly had not come to the author's notice at the time the paper was written. I fully endorse his views regarding the shortcomings of both dry and wet filters, especially with reference to the carrying over of free moisture by the latter type. In several stations employing various kinds of air filters on different generating sets it has been found that the machines fitted with wet-air filters invariably show a lower insulation resistance than the other generators. Dry filters of the cloth-pocket type, on the other hand, are cumbersome and require frequent attention. The intermediate type of air filter consists of a series of compact cells carried in an angle-iron framework which can be built into the generator foundation or the outer wall of the building, each cell containing a large number of small, thin, copper-plated steel tubes or nipples, on the surface of which is a thin film of very high flash-point, highly viscous oil, which forms the cleaning medium, and extracts dirt, dust and excessive moisture from the air. It may be objected that oil will be carried over on to the alternator windings, but it is claimed that drastic and extended tests have clearly demonstrated that this is not the case. The author states his preference for a closed air system incorporating water-circulated cooling tubes in the foundations of the generator. This undoubtedly offers advantages in certain cases, where the necessary large volume of cooling water is available. It cannot be altogether accepted, however, that the only dirt that can be deposited in the machine is that contained in the original volume of air in the circulating system. The system will not be hermetically sealed, and with the constant heating and cooling of the air, as the machine is put on load or shut down, there is bound to be a certain amount of "breathing" action, in the course of which some additional dirt will doubtless find its way into the ducts. I would suggest that provision for this breathing action should be made at some definite point in the air-circulating system, preferably in the sides of the straightest and longest section of the air duct, and that this provision should take the form of one or two cells containing the oil-film filtering medium. These cells, being placed with their faces parallel to the direction of air flow, would not cause any influx of air under normal circumstances, but would permit the air-volume balance to be maintained during expansion and contraction through a regulated path which would clean the make-up air, instead of permitting it to find its way in through devious paths, carrying dirt with it. Where insufficient cooling water is available to permit the use of the closed air system, the oil-film filter in conjunction with a system of air dampers as recommended by the author on pages 774 and 775 should give equal security against fire risks. In fact, taking all points of view into consideration, the oil-film filter may be regarded as preferable even to the closed air system, as with the latter there is some possibility of water leakage from the cooling coils causing moisture to be deposited on the alternator windings. I have experienced trouble of this nature in connection with totally enclosed motors, with water-circulated cooling coils in their base plates.

Mr. F. H. Williams (*communicated*): The latter portion of the paper detailing the research on field suppression forms a valuable addition to the published data dealing with this subject. It is interesting to learn that the squirrel-cage system formed by the slot wedges and the rotor body, in addition to its well-known damping effect, also assists in limiting the voltage-rise when the field is broken without a discharge resistance. It has always seemed to me, however, a mistake to allow the end bells to form part of this squirrel-cage system. When a turbo-alternator is short-circuited there is a certain amount of flashing in the air-gaps round the rotor, due to the eddy currents arcing from the rotor body or slot wedges to the end bells. Similar arcing will take place when the field

is opened, the severity depending on the quickness with which the field current is interrupted. Since the modern tendency in rotor construction is to use greater peripheral speeds and hence to increase the stresses in the rotor body and end bells, it would increase the reliability of the rotors if steps were taken to prevent the flow of eddy currents into the end bells and the consequent possibility of local heating. It is obviously not easy in practice to do this by introducing any ordinary insulating medium between the rotor and the end bell, but, as the flashing is due to the currents which flow mainly on the surface, the same effect could be produced by turning a radial slot at each end of the rotor body close to the end-bell fixings. This could be as narrow as the tool would allow, and should be at least as deep as the winding slot, preferably as deep as possible. To prevent the slot wedges from carrying the eddy currents past this gap, it would be necessary to insert an insulated wedge at the gap, or else to leave an air-gap in the wedges.

[The author's reply to this discussion will be published later.]

ADDRESS TO THE WESTERN CENTRE

By J. S. Highfield, President.

(*Address delivered at* Cardiff, *6th February*, 1922.)

Commerical Development.

When we come up against any really difficult and complicated problem, the first general tendency after we have cleared our minds of the inevitable inclination to think it the easiest thing in the world, is to start afresh to tackle it from a new angle. We try to win clear of past muddles by starting from the beginning. So far as our minds are concerned this, the commonest of all methods, is the right one and, if theories alone are involved, every advantage results from the method. In life, we know that the embryo of the higher mammals passes through all the stages of evolution from the humblest organism to the finished product. So must we study all principles; it is the only sure way and generally the shortest one. In fact, we must go back to first principles when the task is difficult. When, however, we have to deal with practice, with existing works, with ancient and hard-won rights, with established customs, and particularly with those who own the works and have won the rights, a literal application of first principles invariably fails.

The framers of the Electricity Bill did not give due weight to the value of the properties or to the existing rights of those in whose interests they proposed to legislate. They dwelt on theories and neglected practice. Fortunately, the House of Lords came to the rescue and prevented the Government carrying out a scheme which would certainly have failed and which would have been more costly and wasteful than the Government housing schemes.

This proposed short-cut retarded progress. It has forced us back to more cautious methods, and we who are in and of the electricity supply industry must painfully retrace our steps and start again, and this all hands are manfully doing.

Let me for a moment retrace our road since 1832, the year of Faraday's great discovery of electromagnetic induction—his discovery that by moving a closed conductor through a magnetic field an electric current was generated in the conductor. Let anyone contemplate the tiny apparatus used by Faraday and consider all that has sprung from that apparently humble source and then consider the magnitude of the mind that in a few years conceived the phenomenon, and in a few days of fruitful experiment, directed with exquisite skill, resolved the problem and found the key to unlock the golden gates that opened the way to all the work of the past 80 years. Longfellow, I think it was, wrote on viewing the statue of Isaac Newton at Cambridge: "The marble image of a mind for ever wandering through strange seas of thought alone." Newton led directly to Maxwell who, as Mr. Atkinson told you last year, interpreted in mathematical language, with his powerful instrument of analysis, the experimental work of Faraday. There followed many years of work of the first importance, and just 50 years after Faraday's discoveries Parliament passed the first Electric Lighting Act in 1882, an Act which stopped all further progress and gave the Germans and Americans their chance to get ahead of English engineers. Dr. Fleming says in his latest work: "Politicians are apt to think that their labours are essential to the work of the community. They are in truth not nearly so valuable as the work of the electrical engineer. In fact, the legislative shackles which have been the politician's work, such as the unwise Electric Lighting Act of 1882 or their treatment of the telephone, have frequently retarded seriously the work of the electrical engineer."

I have quoted before from the Report of the Electrical Trades Committee of 18th April, 1917, and I will use the quotation again:—

"Through the efforts of Faraday, Wheatstone, Kelvin, Swan, Hopkinson, and many others, Great Britain was, and should have continued, first in electrical enterprise. The nation's pre-eminence in all branches of engineering provided a foundation upon which the new and closely allied electrical industry might have been naturally and quickly built up. In order, however, to bring electrical energy into practical use it was necessary to employ cables . . . the installation of which involved interference with streets. . . . Manufacturers of electrical plant have been held back while Parliament and local authorities debated how the distribution and use of electricity might be prevented from infringing conventional conceptions of public privileges and vested interests. . . . While America, Germany, and other countries were eagerly seizing the benefits of electricity, our authorities were busied with the erection of obstacles to its development. Thus for years this country stood still, leaving the field open for foreign manufacturers to gain, both in their own and other markets, a hold which they have never lost. Abroad there were strong encouragements, in Great Britain irksome restrictions, and the evil effects on the British electrical industry justly entitle it now to special remedial measures, which can be secured only by legislation. Such legislation should be passed without delay."

What were the defects of the Act of 1882? It prevented association between neighbouring companies, and allowed the concessions to run for only 21 years, at the end of which time the works could be purchased at less than their cost.

The prohibition against association was in the early beginnings not the matter of great importance which it has since become, but the scheme for purchase at the end of 21 years was fatal and absolutely stopped

progress until the term was extended to 42 years in the Act of 1888—six years of precious time wasted at the very inception of the electrical industry. The reason for imposing the short term was the same as that which imposed similar terms on the tramway undertakings in 1870. It was the theory that it was not right that individuals should obtain profit from public services, but that the citizens should provide their own supplies at cost price. In practice, this meant that local authorities were to borrow money on the credit of the rates and use it for the purpose of supplying electricity charging cost price, cost including interest and sinking fund payments and what the Electricity Act describes as "a margin." It was realized in the early stages that very little progress would be made on these lines because the whole business was experimental and involved considerable risk. Consequently, the 1882 Act was framed with the idea that private persons would risk their money to start the business which the local authorities could acquire at the end of a period of 21 years, at what was assumed to be cost price or less.

The private investor, no matter how optimistic he may be, wants at any rate some chance of receiving his money back with a profit; that is to say, he must have a chance of getting back out of the business over a term of years more than he would get if he were to put his money into fixed interest-bearing securities such as Government stock. It cannot be too clearly recognized that no matter how money is found, whether by loan on the security of the rates or by persuading individuals to invest in common stock, the money in one way or another comes from the savings effected by the individual, and the individual can make savings only out of profits. Consequently, if every individual in the country is prevented from making a profit, there can be no savings, and, therefore, industry must come to a standstill because money cannot be found for providing the plant that makes progress possible.

Alternatively, the greater the number of individuals who make a profit, the greater is the sum available to help forward the progress upon which civilization depends.

The term "private enterprise" is often used, but it should be realized that, even when the municipality finds the money, the scheme, as a rule, is due to private enterprise, and that great enterprises equally in municipal and company work are initiated by a few energetic people. The difference is not in the enterprise, which in a sense is always private, but in the means of finance to give effect to the scheme. In company work, the first blocks of capital are raised mainly on the credit of the individuals starting the scheme and subsequently on the credit of the business itself. If it earn good profits, it can raise money easily and cheaply. In the other application of private enterprise, the money is raised on the credit of the rates from first to last although a municipality, as a rule, will be reluctant to borrow money to enlarge the scheme unless it is reasonably successful.

Charity of the individual citizen with his own money is always blessed, but so-called public charity exercised with other people's money is not so admirable.

To continue the history of the electrical industry, the next important move was in 1900 when, working on Dr. Ferranti's original view that stations should be erected outside a town for supplying over wide areas, a number of companies applied for parliamentary sanction to carry out what have been known as "power schemes." The Acts obtained were a great improvement on the original Electric Lighting Acts in that they gave permanent tenure. Unfortunately, at that time public opinion was far from being convinced of the importance of a supply of electricity. The companies sought powers to supply (*a*) existing undertakings in bulk, (*b*) large users with whose requirements the local plant could not efficiently deal, and (*c*) for all purposes in areas where no distributor existed. The schemes were in general opposed by the municipal authorities, and many urban areas were altogether excluded from the power companies' sphere of operations. They obtained, however, the right to supply in bulk to other undertakers and to supply for power direct to consumers outside the areas of existing undertakers and for light also in a ridiculously arbitrary proportion when a power supply was afforded. Only in the Cornwall Power Act were adequate rights provided. In this case the company was empowered to supply in bulk to existing undertakers and for any purpose in all parts of the area except in the area of an existing undertaker. This left the power company free to render the fullest service while properly protecting the existing undertakers. However, despite opposition in all the industrial districts, power companies were formed. These companies, after 20 years of uphill work, have now established themselves and command, in general, good credit. On the North-East Coast, owing to the fact that the Power Company was able to start with the Newcastle Electric Supply Company supplying the town of Newcastle as a nucleus, very great progress was made, and it is fair to state that it was the enterprise of this Company that showed how a power scheme could be carried out, and proved what benefits resulted to the community from an adequate supply of electricity. This Company also greatly expedited the development of large turbines for electrical generation. At the present time nearly all the electricity supplied outside urban areas is provided by the power companies.

In 1919, the Electricity Supply Bill was introduced—a Bill proposing to set up new machinery for the supply of "cheap and abundant" electricity. In fact, ample provision for such supply was in being, as in all the important industrial areas in the country a power company was already in existence which, by working with the existing municipal or company undertakings could perfectly well have provided all the electricity required, and at that time, had it not been for the uncertainty of further hampering legislation, could have raised ample sums of money to give effect to any schemes that were commercially desirable. This state of affairs was not recognized in the Bill, since in the original scheme it was proposed to set up entirely new District Electricity Boards which were to acquire by purchase all the generating stations and all the works of the power companies and the distributing authorities.

In other words, they were to do the work all over again, and this fact became so clear in the discussions on the Bill that the part of the Bill proposing to set up District Boards was eliminated and there were left in place of the District Boards bodies to be known as Joint Electricity Authorities. I cannot see that these bodies can be of any service unless they are able to raise money, and if, by some subsequent legislation, they are given power to raise money they become merely District Electricity Boards shorn of some compulsory powers. I am conservative in these matters. I like to see steady evolution. I am no believer in the scheme of setting up a vast new authority where adequate authorities already exist. I have seen many instances where the transfer of great undertakings to new authorities has resulted in loss to all parties concerned and has usually resulted in higher prices to the consumer. I have in mind the transfer of the Marylebone undertaking of the Metropolitan Electric Supply Company to the Corporation, and of the telephones to the State, and I think that in the business of electricity supply in any area where there already exists a power company it ought to be possible for those now conducting the business to effect their own arrangements for joint working and a better use of existing assets without the ponderous machinery of Joint Electricity Authorities. In this connection, the scheme proposed by the companies and municipalities in South Lancashire will be watched with much interest. This scheme and the Birmingham scheme, where the Power Company and the Birmingham Corporation propose to work together, seem to me to promise great results. All that is wanted is sweet reasonableness on the part of those conducting the business.

In the Power Company's areas I can see no object whatever in setting up any Joint Authority. If it cannot raise money it can effect nothing; if it be given power to raise money and to erect works it will simply duplicate to some extent the work of the Company, with resulting waste of capital and higher cost.

In areas where there is no power company an operating Joint Authority might be useful, but widely distributed electrical supply is in my view far more likely to succeed if managed by a compact Board working on proper commercial lines rather than by a large mixed public body whose members are directly responsible neither to ratepayers nor to shareholders.

I do not at all believe in the principle of compulsion on the part of the Electricity Commissioners or any other outside authority. Let us take an example:—Assume that in an Electricity District the engineers of two authorities advise their Boards or Councils that the cost of linking up their systems would give inadequate commercial results, although from a technical point of view the scheme might be advisable, and that, consequently, the authorities decide that they will not find the money for the scheme. How, in these circumstances, can an outside authority insist on the linking up being made unless it is prepared to bear the responsibility of the further finance of the undertakings? This kind of consideration is always arising in electricity supply. It may be perfectly right to call in arbitrators to determine points of difference in estimates, but it cannot be right, once the estimates are accepted as sound, that an outside body should have the power to insist on the money being spent unless that body is prepared to find not only the money for the immediate scheme but also the further sums required for the finance of the undertaking. It must, in fact, take over financial liability.

I have spent the past two days with the Chairman of this Centre and Mr. Chamen and I have seen a good deal of the district, and it appears that the problem here is a big one in that the generation of electricity by private plants is on a much larger scale than that by public authorities. The power company in the district has had an unfortunate history, but there is no doubt that recently it has steadily improved its position, and I should think that those who have had the enterprise to support it have fairly earned the respect due to their efforts to save the property and so to help the community.

The power company have formulated a scheme for helping to supply the future demands of the district on a co-operative basis. The proposal, as I understand it, is an extension of the well-tried principle on which it has worked in past years, namely, that those who require electricity should when possible become shareholders in the power company, and they now suggest that municipalities requiring a supply in bulk should contribute to the capital cost of providing the supply by lending money to the company or by acquiring shares. I see no reason at all why the corporations should not acquire debentures, provided they are well secured. The money to be raised will probably be less in amount than they will raise for their own plant, and the security should be greater as the debentures are protected by the share capital. I am not so sure about investing in ordinary shares. It is true, of course, that the risk is no greater than the similar investment in their own undertaking, except so far as supplying power in a scattered district must always be more risky than supplying power in an urban area with a large lighting revenue. Light is a commodity which all must use, and the use of which is not so much affected by trade conditions as the supply of power. In fact, the supply of power in a wide area involves some of the risks run by the ordinary manufacturer and trader. I like the company's scheme and hope it will meet with success, as the great thing is to get to work and carry out any good scheme. We shall all be dead before a perfect scheme is evolved.

It is not my intention to suggest that municipal electricity undertakings should confine their activities to lighting, but that they should supply all the power they possibly can within their areas. I feel that a municipality is not so well equipped for providing power supplies over wide areas, although in many instances the power company might well buy electricity from the municipality.

I read with great interest Mr. Chamen's recent address on financial matters; at the end he drew a pretty picture of what might be if human nature were different from what in fact it is. It was a dainty illustration and not without a solid element of truth. There is no doubt that the real foundation on which improvement in trade, our

own trade, all trade, rests is in a feeling of confidence and security, and above all the removal of grandmotherly Government interference. One of the first elements of such a foundation is that sentiment which enables men of different views and abilities to work together for a common end. Let a group of men decide to accomplish an end and they will accomplish it; that spirit brought us through the war. We have now a common end and I see every reason why schemes such as the South Lancashire scheme and the South Wales scheme should be the success that all desire.

It is to be hoped that the Government will help. The only real help they can give at the present time is to reduce taxation. We hear much about improving efficiency, the more economical use of coal and all sorts of remedies which engineers alone can apply, views often expressed by men who do not know what the words mean. Engineers are always at work on these jobs and after thought and hard toil effect some small percentage savings representing hundreds of pounds. Meanwhile rates and taxes account for thousands of pounds and not only the savings but also portions of the profits are many times wiped out.

Seldom are savings made until real necessity drives, and I hope the Government and local authorities will voluntarily and boldly reduce taxes and rates and then fit their expenditure to their reduced income as most individuals have been obliged to do.

If this be done I see every reason why with good will trade should slowly be restored to a state of prosperity.

DIRECTIONS FOR DETERMINING THE ELECTRIC STRENGTH OF FIBROUS INSULATING MATERIALS.

(Report received from the British Electrical and Allied Industries Research Association.)

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Preface.

In the past there has not been, either in this country or abroad, any recognized standard method of carrying out electric strength tests on insulating materials.

Amongst the factors which influence the result of these tests are the following:—

(*a*) The condition of the material at the time of the test,
(*b*) The time during which the voltage stress is applied,
(*c*) The temperature of the material,
(*d*) The thickness of the material,
(*e*) The electrodes employed, and
(*f*) The test equipment used.

These factors are of particular importance in dealing with the large class of insulating materials having a fibrous base, and this group has been given special consideration.

From what has been said it is evident that the practice of giving a single figure for the electric strength of an insulating material is of no value, unless the various factors which influence the results are either stated or clearly understood.

The suggestions contained in this report have been arrived at after very careful consideration of the various methods which have been used in the past. The adoption of the methods of test given herein is strongly commended to manufacturers and to users of fibrous insulating materials, so that a uniform practice in tests of this nature may be established.

The tests contained in the first part of the report are essentially of a thorough research nature, whilst the abridged tests in the second part of the report are intended for use when a complete investigation of the electric strength is not required. The clauses in the report are not intended as "acceptance" tests in the purchase of insulating materials, although developments of some of them eventually may be capable of adoption for this purpose.

A method of studying the characteristics of fibrous insulating materials subjected to prolonged electric stress under conditions approximating to those existing in the high-tension windings of electrical machinery has been developed in a research on varnished fabrics. This method is described in Appendix II, and is the subject of further research.

Special attention is called to the recommendation that in considering the electric strength of these materials attention should be given to the results obtained when the material is hot and under long continued stress. In the past the electric strength has often been determined at air temperature; it is sug-

gested, however, that for comparative purposes the latter figure should be obtained also.

The Director of the E.R.A. will value any criticisms from those who have occasion to use any of the tests given in this report.

Part I.—RESEARCH TESTS ON ELECTRIC STRENGTH.

The following methods for the determination of the electric strength are recommended when the characteristics of the material are not known, and when a thorough investigation is required to ascertain the electric strength of the material under probable service conditions.

1. General.

It is of primary importance in the case of fibrous insulating materials that the recognized electric strength be that of the material when hot and under long continued stress.

It is desirable to test materials at temperatures appreciably above their intended working temperature.

2. Preparation of Material Previous to Test.

The ability of a material to withstand a damp atmosphere may be due to

(*a*) The material itself being non-absorptive.
(*b*) Additional protection given by a surface skin either developed during manufacture or added subsequently.

In the latter case the specimens shall be prepared for test in the following manner :—

(i) When determining the properties of the piece * as received the protective surface layers of (*b*) shall be retained.

(ii) When determining the properties of the material itself it is necessary to exclude the additional feature (*b*) by making tests upon sections cut from the material and having the surface layers removed at all points.

The results should in each case state how the specimen has been prepared for test.

3. Conditioning of the Material Previous to Test.

As the electric strength of fibrous insulating materials is largely influenced by their moisture content, it is desirable that the characteristic curves referred to later should be obtained for as many as possible of the following conditions :—

(*a*) *" Normal " Condition.*

This is obtained by permitting the material to absorb its normal quantity of moisture by exposing it to the conditions stated in Appendix I for the period therein stated.

(*b*) *" Dry " Condition.*

This is obtained by removing from the material as much as possible of its free natural moisture, by means of the heat treatment recommended in Appendix I.

* Such as a finished insulator, a varnished washer, etc.

(*c*) *" Damp " Condition.*

This is obtained by exposing the material to an atmosphere of 100 per cent relative humidity under the conditions stated in Appendix I.

(*d*) *" Tropical " Condition (for use when required).*

This is obtained by exposing the material to an atmosphere of 100 per cent relative humidity under the conditions stated in Appendix I.

(*e*) *" Recovered " Condition.*

This is only to be used when testing varnished silk, varnished cloth, varnished paper, or where specially called for. The specimens are to be dried at 75–80° C. for 8 to 15 hours and subsequently exposed to " normal " conditions for 1 week.

Note (i).—If in (*c*) or (*d*) the material is removed from the atmosphere of specified humidity before testing, precaution must be taken to prevent appreciable change in electric strength from this cause.

Note (ii).—When testing sheet material at the temperatures given in Clause 7, the electrodes should be raised to the high temperature before the material is removed from the atmosphere of specified humidity.

4. Tests in Air or Oil.

It is often more convenient to immerse the sample under oil whilst the electric strength test is carried out. Under certain conditions the breakdown voltage obtained when the material is tested in oil is not the same as the breakdown voltage which would be obtained if the material were tested in air. Tests under oil are permissible under the following conditions :—

(*a*) When the thickness in relation to the other dimensions is such that the specimen cannot be conveniently broken down in air.
Materials which are liable to be dissolved or changed in any way (except by absorption as mentioned below) must not be tested in oil.
(*b*) When the material is intended for use in oil-immersed apparatus.
Materials which are capable of absorbing oil must not be tested in oil unless they are to be employed in oil-immersed apparatus. In the case of materials which are intended for use in air and also in oil-immersed apparatus it is desirable that the effect of a damp atmosphere [Clause 3 (*c*)] on the electric strength should be ascertained both in air and in oil.

5. Method of Expressing Electric Strength.

A single value for the electric strength of these materials is of practically no use unless the time of application of the voltage, the temperature and the thickness of the material are either stated or clearly indicated.

Instantaneous values obtained on a rapidly applied test are usually very high and misleading, being out of all proportion to the electric strength obtained by the sustained conditions of practice.

The electric strength shall be given in the form of a series of curves in which the actual breakdown voltage, R.M.S. value (0·707 of the maximum value), is plotted against time and temperature as shown in Figs. 1 and 2

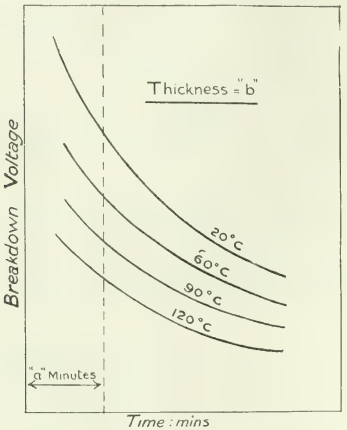


Fig. 1.—Time-voltage curves at various temperatures.

respectively; and in volts per mil against thickness as shown in Fig. 3.

In the case of tubes the voltage gradient across the layers adjacent to the inner electrode theoretically exceeds the voltage gradient across the other layers. On the assumption that the dielectric fails when the voltage gradient on the innermost layers exceeds the rupturing gradient of the material, the electric strength of the material is not that obtained by dividing the breakdown voltage by the thickness as in the case of flat sheet. To correct for the inequality in the voltage gradient across the various layers of the tube, the actual values obtained by test shall be multiplied by the ratio of the maximum stress to the mean stress for the appropriate ratio of outside diameter to inside diameter. The necessary values for this purpose are given in Table 1.

TABLE 1.

Outside Diameter / Inside Diameter	Maximum Voltage Stress * / Mean Voltage Stress †
3	1·82
2	1·44
1·5	1·23
1·3	1·15
1·2	1·10
1·1	1·045
1·05	1·020

$$* \text{ Maximum stress} = \frac{V}{r \log_e R/r}$$

$$\dagger \text{ Mean stress} = \frac{V}{R - r}$$

where V = breakdown voltage,
R and r = outside and inside radii respectively.

6. TIME-VOLTAGE CURVES.

(*a*) In carrying out electric strength tests it is important to obtain time-voltage curves showing the breakdown voltage over the time range from 0·5 minute to the time required for the breakdown voltage to become approximately independent of the time.

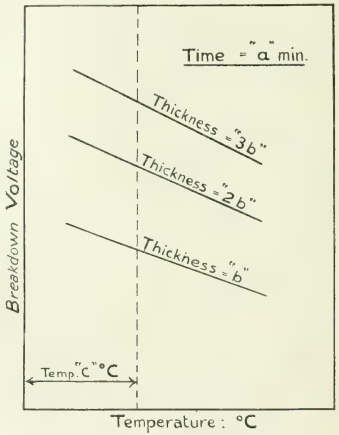


Fig. 2.—Temperature-voltage curves for various thicknesses.

NOTE.—When the dielectric is tested hot the time required for the breakdown to become sufficiently independent of the time of application of the voltage may be about 10 minutes. When, however, the tests are carried out at air temperature (about 20° C.) the time may be considerably longer.

(*b*) In special cases transient voltage tests may be desirable.

7. TEMPERATURE-VOLTAGE CURVES.

It is desirable that time-voltage curves should be carried out at the following temperatures :—

20, 60, 90 and 120 or 150° C. (see Fig. 1).

The 120 and 150° C. are alternative, the latter being applicable to mica products and other heat-resisting materials (i.e. B.E.S.A. Class B insulation).

For a selected number of time values on the time-voltage curves a temperature-voltage curve should be drawn similar to Fig. 2.

8. Thickness-voltage Curves.

(*a*) When the material is supplied in more than one thickness it is further desirable that sufficient of the foregoing temperature-voltage curves (Fig. 2) should be obtained to enable the thickness-voltage curve to be plotted for definite time and temperature conditions, as in Fig. 3.

(*b*) One of the thickness-voltage curves should be plotted from the one-minute values and another from the values obtained when the breakdown voltage is sufficiently independent of the time during which the voltage is applied (see curves in Fig. 3).

For both the above curves the recognized standard

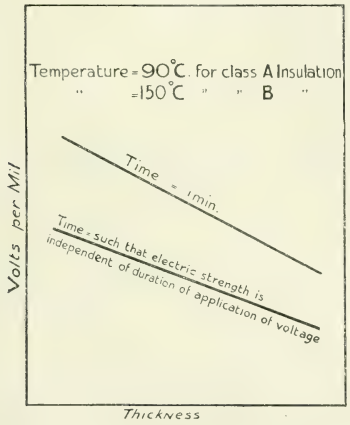

Temperature = 90°C. for class A Insulation
" = 150°C " " B "
Time = 1 min.
Time = such that electric strength is independent of duration of application of voltage
Volts per Mil
Thickness

Fig. 3.—Curves showing variation of electric strength with thickness.

temperatures are 90° C. for B.E.S.A. Class A insulation and 150° C. for B.E.S.A. Class B insulation.

Note.—In plotting thickness-voltage curves, the values on the vertical axis should be in terms of volts per mil, and not in terms of breakdown voltages.

9. Calculation of Electric Strength.

(*a*) *Diagrams.*

For drawing the time-voltage curves sufficient tests shall be made to enable fair curves to be drawn over the time range under investigation.

In order that some idea may be formed of the uniformity of the material, all the experimental values are to be indicated, and when considerable variation is found, this fact should be specially mentioned.

As the temperature-voltage curves are taken from the mean curves drawn through the values obtained on the time-voltage tests, the experimental points cannot be indicated on these or on the thickness-voltage curve.

(*b*) *Measurement of Thickness.*

The thickness of the dielectric shall be measured by means of a micrometer or other suitable method.

10. Test Equipment.

(*a*) *Output of Testing Set.*

The output of the testing set shall be sufficient to maintain on the sample under test the necessary voltage for the maximum period required.

(*b*) *Frequency, etc.*

The frequency of the supply voltage shall be approximately 50 cycles, and if different its value shall be noted. The wave shape shall be as near sinusoidal as possible, and the conditions of the test such as to prevent any high-frequency oscillations.

Note.—In carrying out electric strength tests the voltage should be increased smoothly, preferably by means of a suitable resistance in series with the field of the alternator. When the voltage is varied by means of a resistance in series with the primary of the testing transformer the wave-shape is liable to be distorted. If the wave-shape is not known to be satisfactory, it should be checked whilst a sample is under test, and near the point of breakdown, by means of (i) a spark gap or (ii) a crest voltmeter.

11. Electrodes.

(*a*) *For Sheet Material.*

The bottom electrode shall consist of a flat disc of brass 3 in. diameter by $\frac{1}{4}$ in. thick.

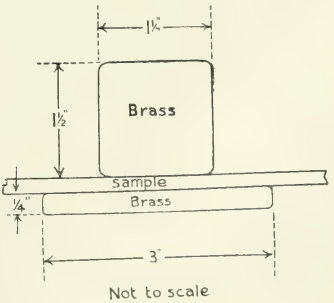


Fig. 4.—Electrodes for sheet material.

The top electrode shall consist of a solid cylinder of brass $1\frac{1}{2}$ in. diameter by $1\frac{1}{2}$ in. high.

The sharp edges shall be removed from the electrodes,

but the radius at the edge must not exceed 1/32 in. (see Fig. 4).

(*b*) *For Small Tubes* (*up to about* 3 *in. diameter*).

The outside electrode shall consist of a band of sheet metal 1 in. wide.

The inside electrode shall consist of a cylinder with the ends rounded to a radius of ½ in., or when a cylinder with rounded ends cannot conveniently be obtained, a sheet metal cylinder sprung into place may be employed. The length of the inside electrode shall be not less than 1 in. plus three times the thickness of the wall of the tube (see Fig. 5).

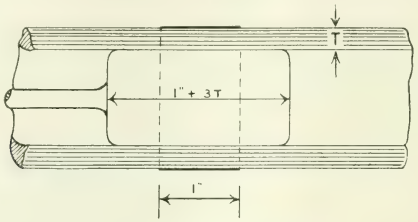


Fig. 5.—Electrodes for small tubes.

(*c*) *For Large Tubes* (*often called Cylinders*).

The outside electrode shall consist of a strip of sheet metal 3 in. wide.

The inside electrode shall consist of a disc 1½ in. diameter of sheet metal sufficiently flexible to conform to the curvature of the cylinder ; this disc of sheet metal to be pressed against the inside of the cylinder so as to make good contact over the whole of the area of the disc (see Fig. 6).

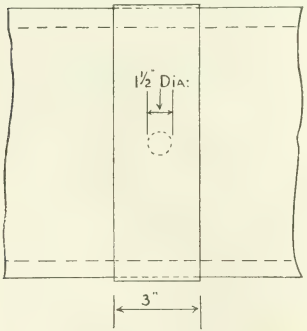


Fig. 6.—Electrodes for cylinders.

(*d*) *Suggestions for obtaining good Contact.*

Sheet zinc about 1/32 in. thick has been found convenient for springing into tubes for forming the inside electrode.

Soft aluminium foil from 2 to 5 mils thick has been found convenient for use as the outside electrode on tubes.

When the surface of the specimen is irregular or any difficulty is experienced in obtaining good contact, it is recommended that tinfoil should be interposed between the electrode and the dielectric.

12. Longitudinal Breakdown.

Materials which are composed of a number of superimposed layers generally have a different electric strength in the direction parallel to the laminæ from that in the direction at right angles to the laminæ. All such material should, therefore, be subjected to a longitudinal breakdown test carried out as follows :—

(*a*) *Tubes.*

Cut out a complete cylinder from the tube, or in the case of tubes of large diameter, a portion of a cylinder, with a cross-sectional area of about 1 sq. in., if possible. Clamp hand-tight between parallel metal plates, immerse in oil at 90° C., apply voltage between the metal plates, and ascertain the voltage required to produce breakdown in one minute [for method, see Part II (*c*), p. 799]. The length to be tested to be 1 in. and also 2 in. (see Fig. 7).

(*b*) *Sheet Material.*

Cut strips of 1 in. and also of 2 in. wide respectively, and of any convenient length. Test singly in a manner similar to Tubes (*a*) above.

(*c*) *Alternative Method for Tubes and Plate.*

If it is found by the above tests, or it is previously known, that the longitudinal breakdown of the material is greater than the breakdown of an equal length of oil, the material should be tested by the following method :—

Drill two holes, using a 5/64 in. twist drill, in the same

straight line, in two opposite edges of the material. Insert pieces of 1/16 in. brass rod with square ends, as shown in Fig. 8, thereby making the path through the material less than the path across the surface of the material. It is essential that the two holes should be opposite each other and that the brass rod should *not* be a tight fit in the holes. The material should be drilled slowly so that the drill does not exert any wedging action which would tend to open up the layers.

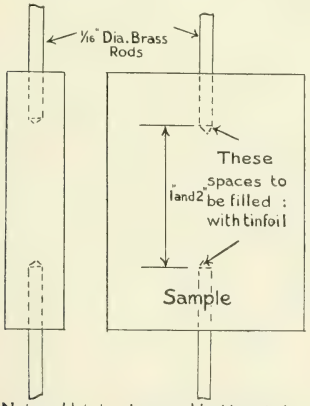

1/16" Dia. Brass Rods
These spaces to be filled : with tinfoil
1" and 2"
Sample
Note: Hole has tapered bottom but brass rods are to have square ends

Fig. 8.—Alternative arrangement for longitudinal breakdown.

13. Tests at High Frequencies.

Investigations are being carried out with a view to drafting a suitable test to determine the electric strength at high frequencies.

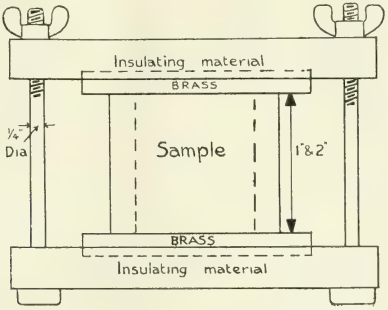


Fig. 7.—Arrangement of specimen for longitudinal breakdown test.

Part II.—ABRIDGED TESTS ON ELECTRIC STRENGTH.

The following methods for the determination of the electric strength of fibrous insulating materials are recommended when it is not required to ascertain the characteristics of the material in such detail as provided for in Part I.

(*a*) *Conditioning.*

(i) Prior to test the materials shall be exposed to the "Normal" atmosphere as detailed in Clause 3 (*a*).

(ii) If the material claims to have special non-absorptive properties, it shall also be tested after exposure to either "Damp" or "Tropical" conditions, as detailed in Clause 3 (*c*) and (*d*).

(*b*) *Method of Expressing Electric Strength.*

The recognized method of expressing the electric strength of materials subjected to these abridged tests shall be the voltage required to produce breakdown in one minute when the material is at a temperature of 90° C. For ease of comparison the volts per mil, followed by a statement of the thickness to which it refers, shall also be given.

In the past it has usually been the practice to take the electric strength of the material at air temperature, and by a rapid application of the voltage. Until the recognized standard, of one minute at 90° C., has come into general use, it may occasionally be desirable, for comparative purposes, to determine also the electric strength when the voltage is rapidly applied at air temperature.

(*c*) *Time-voltage Curves.*

In order that the voltage required to produce breakdown in one minute may be accurately determined, the following procedure is recommended :—

To obtain some idea of the breakdown voltage of the material a test should be made by increasing the voltage as fast as is consistent with obtaining satisfactory readings of the measuring instrument. The material should then be subjected to two-thirds of the breakdown voltage obtained on a rapidly applied test, and the time required to produce breakdown noted.

From the results of this test an approximate idea can be obtained of the voltage which will produce breakdown in about one minute; this estimated voltage should then be applied and the time required to produce breakdown noted. From this latter result, a still closer approximation can be made. In addition to the rapidly applied test, at least five breakdowns should be obtained on each sample, and the values plotted on a time-voltage curve, similar to Fig. 1, but for the time range round one minute only. From this curve, the voltage required to produce breakdown in one minute can be determined.

(*d*) *Other Factors.*

In conducting the abridged tests for electric strength, the conditions specified for the other factors entering into electric strength tests are the same as for the research tests dealt with in Part I.

APPENDIX I.

Details of Temperature, Time and Humidity required for the Various Conditions and Materials in Conditioning of Samples previous to the Electric Strength Test.

Condition	Material	Temperature (° C.)	Time (Hours)	Humidity (Relative)
Normal	Treated papers and fabrics	15–25	18–24	75 %*
	Pressboard	15–25	18–24	75 %*
	Leatheroid and vulcanized fibre	15–25	18–24	75 %*
	Varnish-paper boards and tubes	15–25	18–24	75 %*
Dry	Treated papers and fabrics	75–80	2–3	Low
	Pressboard	75–80	18–24	Low
	Leatheroid and vulcanized fibre	75–80	18–24	Low
	Varnish-paper boards and tubes	75–80	18–24	Low
Damp	Treated papers and fabrics	15–25	18–24	100 %
	Pressboard	15–25	18–24	100 %
	Leatheroid and vulcanized fibre	15–25	18–24	100 %
	Varnish-paper boards and tubes	15–25	18–24	100 %
Tropical	Treated paper and fabrics	45–50	18–24	100 %
	Pressboard	45–50	18–24	100 %
	Leatheroid and vulcanized fibre	45–50	18–24	100 %
	Varnish-paper boards and tubes	45–50	18–24	100 %

* This figure is adopted provisionally, awaiting recommendations from the N.P.L.

APPENDIX II.

Method of Ascertaining the Electric Strength of Materials when Subjected to Long Application of A.C. Stress and Power Frequency.

When in service in electrical machinery and apparatus, insulating materials have to withstand voltage stresses for long periods of time. As the insulating materials are usually in contact with metal parts, one of which is generally at a higher temperature than the insulation, the conditions are such that any heat generated in the insulation itself cannot be readily dissipated.

To investigate the internal heating produced in fibrous materials when under A.C. stress, and to ascertain the highest A.C. stress which the material can endure without loss of insulating property as the result of excessive internal heating, the following test is recommended :—

(*a*) *Apparatus suggested.*

In Fig. 9 is shown a diagram of the connections of the necessary apparatus. Particulars of a set of instruments which have been used for these tests are given below :—

A.C. Voltmeter.—Electrostatic, reading to about 120 volts, capable of being connected across various sections of a suitable potential dividing resistance, connected across the transformer secondary.

Any other type of high voltage measuring equipment may be used.

D.C. Voltmeter.—Reading up to 150 volts in 1 volt steps.

Microammeter.—For leakage measurement. R. W. Paul, of London, N.K. 1035. Resistance about 900 ohms at 20° C. Range, 0–24 microamps. by 0·2 (120 scale divisions).

If the A.C. component is large an instrument of low resistance may be desirable.

D.C. Battery.—Portable type, 25 lead cells or primary cells.

Thermocouple.—Eureka—copper. 6½ in. each of 0·008 in. covered wire and hard soldered to form couple. At the other end the copper is soldered to 3 ft. 8 in. of

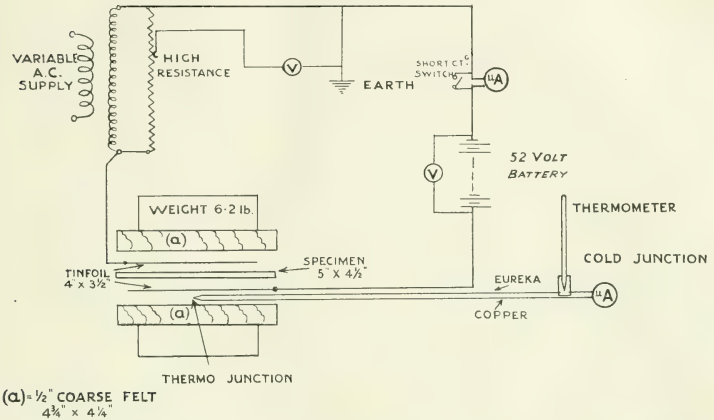


Fig. 9.—Connections for ascertaining the electric strength when the material is subjected to long applications of voltage.

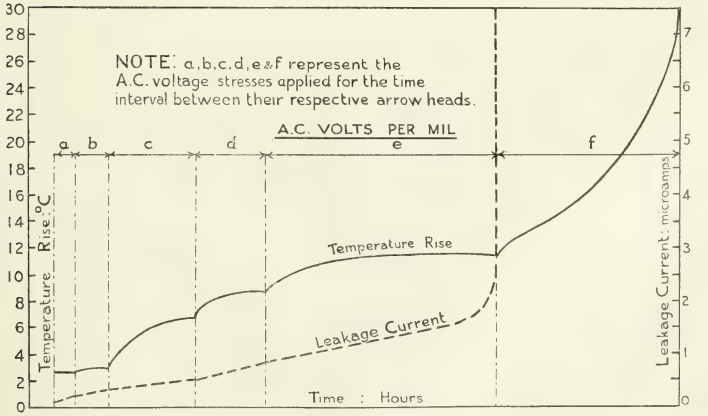


Fig. 10.—Showing method of expressing the results of the test illustrated in Fig. 9.

0·027 in. covered copper wire and the eureka to 3 ft. 8 in. of 0·018 in. covered eureka wire.

From here copper flexible leads are connected to the instrument.

Resistance, about 4·7 ohms at 20° C.

A thermometer is bound to the cold junction with tape.

An eureka series resistance can be inserted to increase the range, but this is not required, except for readings in the unstable range.

Resistance of couple and series resistance = 8·65 ohms at 20° C.

Thermocouple Instrument.—Microammeter by R. W. Paul, London, N.I. 1 135.

Resistance, 5·1 ohms at 20° C.

Range, 0–300 microamps. by 5 (60 scale divisions).

Temperature range :

Without series resistance : 0 to about 65° C. rise
With series resistance : 0 to about 90° C. rise

Air Temperature.—By thermometer 3 in. from edge of specimen, with bulb on the same level.

Felt Pads of coarse green felt, $4\frac{3}{4}$ in. × $4\frac{1}{4}$ in. × $\frac{1}{2}$ in.

Tinfoil 4 in × $3\frac{1}{2}$ in. × 0·0015 in. thick.

(*b*) *Arrangement of Test.*

The material is cut into rectangles each 5 in. × $4\frac{1}{2}$ in. and exposed to " Normal " * condition [Clause 3 (*a*)].

* If the material claims to have any special non-absorptive properties, tests should also be made on material which has been exposed to " Damp " or " Tropical " conditions (Clause 1 (*c*) and (*d*)).

After conditioning, sufficient of these to form a pad approximately 30 mils thick are carefully laid and pressed together so as to exclude entrapped air. On each side of the pad a tinfoil 4 in. × $3\frac{1}{2}$ in. is pressed into contact. The specimen with its tinfoils is placed between two $4\frac{3}{4}$ in. × $4\frac{1}{4}$ in. pads of $\frac{1}{2}$ in. coarse felt and mounted for test as shown in Fig. 9. A thermocouple in contact with the centre of the lower tinfoil measures the temperature attained. In series with the source of high-voltage A.C. are a D.C. battery of (usually) 52 volts and a microammeter by which unidirectional leakage current is measured.

(*c*) *Method of Test.*

An A.C. stress of moderate gradient is applied and maintained till temperature and leakage current attain steady values. The gradient is then increased and again held till results are steady. This procedure is repeated till a gradient is reached at which temperature and leakage current will not settle down to steady values, but rapidly increase to a destructive condition. At this stage, unless interrupted, charring and complete breakdown rapidly follow. The microammeter should be short-circuited or the voltage switched off before breakdown of the specimen takes place.

(*d*) *Method of Expressing Results Obtained.*

The values obtained should be shown graphically as illustrated in Fig. 10. The following should also be recorded :—

(i) Maximum voltage and stress in volts per mil at which the material is in a stable condition.

(ii) Maximum temperature-rise obtained in (i).

DISCUSSION ON

"THE INTERCONNECTION OF ALTERNATING-CURRENT POWER STATIONS."*

Discussion before the North-Eastern Centre at Newcastle, 23 January, 1922.

Mr. E. Fawssett: In connection with the general subject of this paper it may be of interest briefly to describe some apparatus that has been developed for indicating, at a point remote from the measuring point, interchanged power. The load controller, or the head office, or the power station, often needs to know what is happening some miles away at a distant substation or point of interchange with another undertaking, and, while sometimes this information can be obtained by telephone, there are many obvious objections to this method. Simple alternating-current indicators are out of court where considerable distances are involved, owing to the necessarily high resistance of the pilot connection, probably 1 000 ohms and more per pair circuit. A quite robust direct-current indicator requires some 25 000 times less power to operate it than a very sensitive alternating-current instrument, so this property is taken advantage of through the intermediary of a thermopile. A small battery of thermo-junctions is warmed by a heater carrying a submultiple of the alternating current to be measured, these junctions giving an electromotive force up to 40 millivolts, proportional to the square of the alternating current. This is ample to operate a switchboard unipivot high-resistance indicator through a pilot of more than 1 000 ohms, allowing over 20 route-miles with a pilot having a resistance of 24 ohms per mile. This simple measurement may often suffice, but an accurate indication of alternating-current power is readily obtainable and has been in commission on the North-East Coast for some five years between two power stations 9 miles apart. If we take two heaters each with its own bank of couples, one heater being supplied with a current due to the voltage, and also one due to the current to be measured, so connected as to give the vector sum, the other heater being supplied similarly but so connected as to give the vector difference, then the electromotive force of the couples in the first case is proportional to the square of $(V + A \cos \theta)$ and in the second to the square of $(V - A \cos \theta)$. These electromotive forces are arranged to oppose each other, the net electromotive force being therefore proportional to $VA \cos \theta$, i.e. the power in the circuit being measured. This electromotive force can be transmitted and indicated in the same way, the instrument in this case having a straight-line law. Other quantities, such as reactive kVA or the synchronism (or lack of it) between two supplies, can be similarly indicated. This general method should be of great use in the near future.

Mr. C. Whillis: I am interested in the question of interconnecting networks from the point of view of their effects on contiguous telegraph and telephone plant, and I should be glad if the authors would give some information as to the practice with regard to multiple earthing on such systems in America. What type of transmission line is used for the extra-high voltages, and what is the effect on telegraph and telephone circuits in the area of an unbalanced earth fault on the power system?

Mr. W. H. Palmer: We in the North usually think of the 20 000-volt underground cable going south, and in this respect I think a single interconnecting link—useful though it may be—gives rather a false sense of security. In the early days 60 to 70 amperes on this cable was thought to be a heavy load, but during the war it carried over 6 000 kW. It held out, however, and in no small measure contributed considerably to the successful supply of electricity on the North-East Coast. A bone of contention which usually led to heated arguments was "wattless" current; and we in the Tees area always maintained that we carried all the wattless current for the Tyne area, and they in turn stated that they carried our wattless current.

Messrs. L. Romero and **J. B. Palmer** (*in reply*): The device described by Mr. Fawssett for indicating alternating current, power, etc., at a distance by the use of direct currents through small pilot wires, should prove of very great value on interconnection schemes. We have in mind the particular case of an interconnecting feeder terminating at either end at a substation, where the attendant would have no control of the power interchanged except by the aid of the telephone to the power station. In an interconnection of this kind, Mr. Fawssett's device would make it possible to control closely from one power station the amount of power interchanged between the two systems, without the aid of the telephone.

In reply to Mr. Whillis, there are very many instances in the United States where power companies earth the neutrals of their high-voltage transformers as and when required, with the result that on any one system there may be numerous earths. In one case with which the authors are familiar, there are no less than 150 earths on the high-voltage system. Transmission lines constitute fairly extensive networks and are of the usual type as regards spacing and insulation, and the authors believe that the telephone companies have less trouble in the aggregate with transmission systems having multiple earths than they do with completely insulated systems.

The double interconnecting link mentioned by Mr. W. H. Palmer is certainly preferable to a single one from the point of view of security, but there must nevertheless be many cases where the extra security provided by a stand-by feeder would not justify the extra cost, particularly having regard to the very high degree of reliability obtained with modern extra-high-pressure underground cables.

* Paper by Messrs. L. Romero and J. B. Palmer (see page 287).

NORTH-WESTERN CENTRE, AT MANCHESTER, 7 FEBRUARY, 1922.

Mr. J. S. Peck: There are several problems which are of special interest and must occur in almost every case. Suppose it is wished to transmit a certain amount of energy, at a certain power factor, from one station to another. The question is: What voltage difference is required between the two stations, and also what would be the power factor of the load on the sending station, assuming that a certain power factor is required on the receiving station? Again, if the boost is fixed, or the difference in voltages which is allowed between the sending and receiving station has been settled, what is the maximum amount of power in kilowatts that can be delivered at a certain power factor? The third question is: Supposing that a voltage difference is not allowed between the two stations, what will be the power factor, assuming that it is desired to deliver a certain amount of energy at one station or the other? These are the most usual problems in connection with this subject, and the authors have given certain formulæ for determining, in some cases with considerable exactitude, in others approximately, the solutions of these problems. I think it would have added considerably to the value of the paper if they had worked out definite examples, and I suggest that they should do so in their reply. It seems to me that the problem can be looked at in this way. There are only four voltages which come into question, i.e. the voltage at the receiving end, the voltage at the sending end, the ohmic drop and the reactive drop in the line. If it be assumed that a certain current or a certain load has to be transmitted, and the power factor at which that must be received be fixed, then the voltage at the receiving end and the power factor can be determined at once. From the kilowatts and power factor the current can be found and, knowing the constants of the interconnector, the ohmic drop and the reactive drop can be calculated. By applying the Mershon chart it would be possible, in a very few moments, to solve almost any problem that might arise. Fig. A shows the Mershon chart. The numerals 10, 20, 30, etc., represent power factors and voltage. Suppose it is desired to deliver a certain amount of energy at 80 per cent power factor and assume that under this load the ohmic drop on the line (IR) is 6 per cent and the reactive drop (IX) is 10 per cent. From the intersection of the 80 per cent power-factor line with the 100 per cent voltage circle, draw the horizontal line $IR = 6$ per cent. From the end of IR erect the vertical line $IX = 10$ per cent. Then IZ= the impedance-drop in per cent and E_2 = the value and phase angle of the voltage at the sending station. It will be seen at once that the value of E_2 is 111 per cent and the power factor at the sending end 77·5 per cent, approximately. This means that the voltage at the sending end must be 11 per cent higher than that at the receiving end. This is the same construction as the authors show in Fig. 1, the advantage of the chart being that the results may be read off without drawing in any of the dotted lines shown in the diagram. Again, suppose the voltages at both stations are the same, and that the current in the interconnector is such as to give 7 per cent ohmic and 11 per cent reactive drop in the interconnector; by trial find a point on the 100 per cent voltage circle, such that when IR is drawn equal to 7 per cent and $IX = 11$ per cent, the end of IX will fall on the same circle; then $E_1 = E_2$, and the power factor at the sending end is approximately 89 per cent and at the receiving end 82 per cent, both leading. From these two examples the utility of the

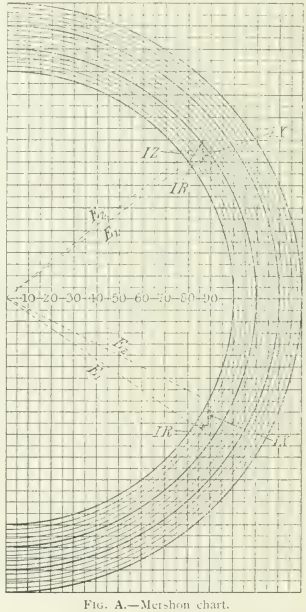


FIG. A.—Mershon chart.

chart will be apparent. The paper takes account only of the ohmic and reactive drops in the line. If there is capacity in the line the conditions become rather more complicated. The authors have not attempted to deal with this, but it would be well if they could indicate in general how capacity in the interconnector would affect the operating conditions. I think it will improve them, providing it is not too great; i.e. it will reduce the boosting effect required. The paper offers a great many points for discussion. The question of

regulators for securing the boost is, in itself, a large subject. The question of synchronizing power has been touched on by the authors in a very general way. Their formulæ might be applied to working out some specific examples of synchronizing power, from which conclusions could be drawn which would be an advantage to anyone considering the question of interlinking.

Mr. H. A. Ratcliff: When discussing the subject of the paper it is very necessary to get a correct perspective, because everything depends to such a large extent on local conditions. For that reason Appendix III is both interesting and valuable, because in a discussion of this nature reference to American conditions is inevitable. It should be recognized, however, that American conditions are not exactly comparable with those which are likely to obtain in this country. In the first place the line pressures are higher and most of the transmission is by means of overhead lines having a fairly high reactance, whereas in this country line pressures have been, and still are, comparatively low, and much of the transmission has been, and will be, by means of underground cables having a comparatively negligible reactance. Moreover, in America the distances covered are very much greater than in this country; and we are not likely to have 200-mile lines just yet. Offset against that, however, is the fact which the authors have mentioned, that close line-regulation and power-factor control have not usually been regarded as matters of much importance, although I understand that in the case of one or two of the more important American interlinked systems rather more attention has recently been given to power-factor control, for which purpose very large induction regulators have been installed. It appears very evident from the information given in Appendix III that the successful operation of the extensive interlinked systems depends to a very great extent on what may perhaps be referred to as the autocratic powers possessed by the "load despatcher," and there is no doubt that if we are to have really successful interlinking in this country the services of some such official will be necessary. "Load Controller" would, however, be a better title than "Load Despatcher." I think that the first important fact demonstrated by the paper is that the real cause of all the trouble is the line loss or, incidentally, the pressure-drop due to line resistance. A certain amount of reactance is beneficial, and in fact is usually essential in order to ensure that there shall be sufficient synchronizing power. If the busbar pressures at the two ends of a line are equal and there is no provision for boosting, it is impossible to transmit power (as distinct from idle kVA) unless there is a sufficient amount of reactance in the circuit. This will be evident from the conditions shown in Fig. 1 for equality of E_1 and E_2. That is perhaps an additional reason for having plenty of reactance in the transformers at either end of the line. A certain amount of reactance is essential in large transformers in order to limit the extent of the current in the event of a short-circuit, but it appears possible that in some cases transmission requirements may necessitate an increased amount of reactance in the transformers. It will be obvious from the information given in the paper that there is every advantage in having a high transmission pressure, and the tendency in the future will be to adopt higher pressures. As a rule it pays to change over from 6 600 to 33 000 volts, for example, when the resultant saving on the line loss will counterbalance the increase in the capital charges on the higher-voltage equipment; but in view of the important transmission requirements referred to in the paper it is evident that in many cases it may be advisable to adopt the higher pressure for a shorter transmission distance than would be justified by economic considerations. In this connection certain characteristics and advantages of 33 000-volt cables are of interest and importance. Naturally such cables are comparatively expensive, and further, owing mainly to the high cost of jointing, they are very expensive to lay. Moreover, in the light of present knowledge on the subjects of dielectric loss, and contraction and expansion of the conductors, it is not considered advisable to push the current density too high. For these reasons the tendency is to employ conductors having a fairly large sectional area. This, however, involves a still further reduction in the current density, owing to the proportionally smaller cooling surface on the larger conductors. For 6 600-volt distribution a 0·15 sq. in. 3-core cable is a size very frequently employed. For such a cable the permissible full-load current is about 210 amperes, giving a pressure-drop due to conductor resistance when hot of 1·87 per cent per mile. On a 0·3 sq. in. 33 000-volt cable with a full-load current of 315 amperes, the corresponding pressure-drop would be only 0·272 per cent per mile, representing a reduction in the ratio of 6·9 to 1, which naturally tends to simplify many of the problems incidental to interconnection referred to in the paper. The average distance involved in most of the proposed interlinking schemes is not more than 10 miles, and with a 0·3 sq. in. 33 000-volt cable the total resistance-drop would be 2·72 per cent and with, say, 0·5 per cent in the transformers at each end of the line the total overall drop would be about 4 per cent. Consequently a comparatively small amount of boost would be necessary in order to transmit at approximately unity power factor. With the amount of reactance usual in transformers of the type concerned no boost would be necessary if the load could be transmitted at an average leading power factor of about 0·93. With lagging power factors the amount of boost would naturally have to be correspondingly increased. The treatment of the technical features in the paper is very thorough indeed and the various diagrams and formulæ are most instructive and valuable. I should like to suggest, however, that Fig. 1 would be more instructive if the circle showing the locus of the sending voltages were added. The relative positions of the two circles as shown in Fig. B enable one to visualize much more clearly what happens as the voltage vectors swing round, and it will be obvious that below a certain value of the power factor (lagging) there is very little change in the amount of boost required. The maximum value occurs when angle θ = angle α. It is also obvious from Fig. 1 that when $E_1 = E_2$ it is not possible to transmit power without an appreciable amount of

reactance in the line. The advantage of the "phase control" or leading-power-factor method of transmitting is that conditions are so adjusted that the reactive and ohmic drops in the line are exactly balanced, and being balanced for one load they are balanced for all loads, and consequently there is not the great change in power factor with load which occurs with a fixed amount of boost. The method of balancing the ohmic drop by a fixed boost is very useful when transmitting power in one direction only, but, as the authors point out, the great disadvantage is that the power factor varies with the load, and on light loads it may attain a very low lagging value. Moreover, the conditions are not reversible as it is possible to transmit in only one direction. A wide variation in the lagging value

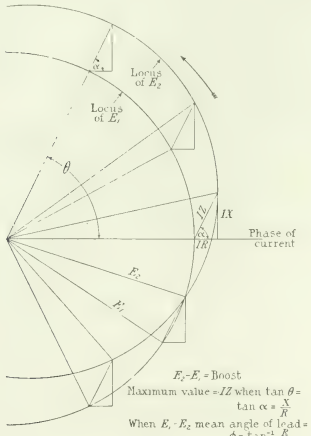


FIG. B.

of the power factor can be avoided, to some extent, by providing the boost for something less than full load, and that is perhaps a fair arrangement because the power factor varies with the load between a leading and a lagging value, and consequently the adverse conditions are not always experienced at one end of the line only. The ideal arrangement is method (3), for it permits of transmission in either direction, and the power factor can be adjusted to any desired value. The only objection to the method is the expense and complication involved, and it is therefore a matter for careful consideration, taking all the circumstances into account, as to whether the conditions are such as to justify the additional expense and complication for the particular case in question. With regard to the type of regulator, I am of the opinion that on the whole the advantages are with the induction type. They are robust, can be well insulated if immersed in oil like an ordinary transformer, are not complicated, and have no moving contacts carrying heavy currents. They give an infinite range of adjustment and are very suitable for hand, power, or automatic operation. I should like to ask the authors whether they can give any figures for the relative cost and efficiency of the two arrangements shown in Figs. 6 and 7. The first arrangement has the advantage that it avoids the additional link in the extra-high-tension line, but much will depend upon the relative cost of the two arrangements and the relative efficiencies. Apart from cost the only real disadvantage with the induction regulator is the phase displacement which it introduces into a line; and moreover, it is not a constant displacement but varies with the extent of the boost from a minimum to a maximum, and back again to a minimum. The effect is not serious, however, unless the regulators are installed on parallel circuits, in which case circulating currents may increase the I_2R losses, and the operation of isolating links, etc., may at times demand special care. The difficulty may be overcome, if necessary, by the use of double regulators having the phase rotation reversed in one as compared with the other, but naturally such an arrangement involves additional expense and complications. The paragraph at the foot of page 290 brings home very clearly the meaning of "line loss plant" and, further, there is also the necessary additional capacity in the generating plant. The authors have shown very clearly what an important bearing power factor has on transmission conditions. The power factor is really the crux of the whole matter, and in that connection I agree with the authors that in interlinking schemes there should be a certain amount of give and take between the various authorities on the subject of power factor; obviously they cannot all have it to their own advantage. Such co-operation must, of course, be subject to the condition that the operation of the plant and transmission lines involved is carried out in such a way as to conduce to the highest all-round economy. It will be possible to attain that result only by having centralized control by a thoroughly qualified controller, fully acquainted with the plant and the load conditions in the various stations, and the characteristics of the several transmission lines. I do not quite follow the argument at the bottom of page 292, because any supply undertaking would endeavour to induce, if possible, a consumer to improve a power factor as low as 0·7. A very important point arises here in connection with the measurement of power factor. It would obviously be unreasonable to say that the power factor must not fall below a certain value, then to install a recording power-factor meter, take a test reading, and say that the power factor had fallen below the guaranteed minimum. There is something to be said for the method which has been adopted on certain systems of installing two single-phase watt-hour meters and arriving at the mean power factor over a period of time from calculations based on the registrations of the two meters during the period in question. This method gives a perfectly equitable mean value, weighted in proportion to the extent of the load and the duration of the load. In connection with

the question of power factor and the transmission of power over interlinking lines, it may be an advantage, in cases where there is old and somewhat inefficient plant at the receiving end of a line (provided the plant is capable of dealing with a lagging load), to allow it to handle as much as possible of the wattless component, and transmit over the line at the most favourable power factor for the more efficient plant in the larger and more modern station. That will perhaps provide an alternative to synchronous condensers which, under special conditions, may serve a very useful purpose, but which I hardly think should be installed unless there is a very strong case for them.

Mr. E. M. Johnson: The question of interlinking is one which will come into greater prominence in the next few years, and I think the main value of the authors' paper will ultimately be found in Appendix III. Reference is there made to the American interlinking systems, and to the high load factors obtained in that country. The same state of affairs exists in Switzerland, where about 1 million kW of generating plant are interlinked throughout the country over an area of about 16 000 square miles. Three hundred stations are interconnected, and load factors of 60 to 80 per cent are common. I gather from the appendix that the authors are of the opinion that these high load factors are mainly the result of the interlinking of distant stations on a single system and, in some measure, to the fact that these stations are hydraulic. I am not familiar with the conditions of supply in America, but I anticipate that the real explanation is to be found in a liberal system of graded tariffs, in the offer of low terms as an inducement to the use of current during off-peak periods (particularly for domestic purposes) and, finally, in the interlinking, practically without respect to distance, of stations and systems having different characteristics both as to load and as to motive power. In considering questions of interlinking it would be well to look beyond the limits of the neighbouring supply undertaking and endeavour to find, possibly at some considerable distance, an undertaking whose load curve is the inverse of one's own, instead of seeking simply to find a local company anxious to form what must otherwise be a temporary alliance.

Mr. W. A. Coates: The authors mention that the contactor-type and face-plate type step-by-step regulator cannot be constructed for pressures over 3 000 volts. I can understand that they have not been *commercially* constructed above that voltage, but I see no technical reason why they should not be constructed for any pressure for which transformers can be built. I should like to know whether it is a purely commercial limitation or whether there is some technical limitation of which I am not aware.

Mr. J. Collinge: The undertaking with which I am connected was linked up with the Lancashire Power Company in 1915. The Company supplied to a small substation about 1 mile away from the power station at a pressure of 10 000 volts, which was transformed down to 6 600. We ran most satisfactorily, connected up with them, and the question of power factor was certainly not troublesome. Later on we found occasion to obtain an additional supply from Manchester, and this resulted in a most interesting and perhaps unique experience in interconnecting systems. The power company, which has an overhead system for the major portion of the distance, Manchester and ourselves were all running together. We synchronized with Manchester at the Salford power station and the power company synchronized with us at their power station and still the question of power factor did not unduly trouble us. Then the question of load adjustment had to be dealt with. That was overcome by the power company agreeing to give us a definite load at their power station and keeping it, so far as possible, owing to the fluctuations of the systems, at that load, and we at Salford arranged the load we took from Manchester. I believe that when the three systems were running in parallel the power company were also supplying power to Wigan, to the South Lancashire Tramways and other townships. Another interesting fact is that the power company's system is earthed and ours at Salford is not, while that of Manchester is earthed on the 33 000-volt side. I do not mean to minimize the importance of power factor. It is undoubtedly most important in setting up interconnecting systems, and in arranging plant for supply it must be taken into consideration. If that is done, then the actual power factor can generally be regulated by other factors to a satisfactory figure, especially in this country where the interconnection systems are short as compared with those in America. It is very important to study the power factor in the case of interconnecting power stations, and to my mind it is equally important that the consumer should also study his power factor and give it very careful consideration. I know of cases where the installation of synchronous condensers at comparatively small cost, compared with the amount of current being taken, has reduced the latter by as much as 50 per cent.

Mr. A. G. Ellis: There is one point which this paper emphasizes and which has not been remarked upon, i.e. the development of extra-high-tension interconnection. Since the date of Mr. Peck's paper we have now in this country quite a number of 33 000-volt underground cable interconnecting systems, and it is not unlikely that in the near future we shall have underground cable systems at considerably higher voltages than this. I should like to call attention again to the author's statement on page 287, under "General Operating Conditions," on the question of transmitting load. This seems to me possibly the most important general statement in the paper. The only way in which the amount of load transmitted can be altered is not by adjustment of the voltage but wholly by the adjustment of the steam supply to the prime mover. This point should be borne in mind when considering the question of the voltage regulator which is primarily concerned with the adjustment of the power factor. Table 1 shows the rôle which the voltage regulator plays in this respect. The authors have dealt practically with a simple case of interlinking two stations, and the vector diagram given in the paper deals with that case very simply. I should have liked to see in the paper the case of three stations interlinked by a ring main. This can be worked out from the vector diagram given

and is a very interesting case. One problem which often arises in this connection concerns the phase angle between the different stations. It may be found impossible to interlink three existing stations without changing some of the transformer connections, or possibly re-winding them for different connections to get the right phase angle around the whole of the system. There is another case on which I should like the authors' opinion, i.e. the case of interlinking two stations by parallel feeders. In the case of an existing plant with two points interlinked by a new 33 000-volt cable and by an 11 000-volt cable from which a local supply is tapped, the line characteristics of the two feeders may be such as to give a large difference in the power factors of the two feeders, and I should like to hear what the authors consider to be the best method of dealing with the wattless current. It would probably involve putting in an induction regulator in one or both feeders, or power-factor adjusters. As Mr. Peck remarked, the question of different types of voltage regulators is almost a subject in itself. In general I think I agree with Mr. Ratcliff that the induction regulator is the most satisfactory type of regulator, and the only reason that it is not always installed is the capital cost. The induction regulator is, generally speaking, a more costly piece of apparatus than the contact regulator referred to in the paper. The installation of induction regulators may be restricted by the limiting size of the induction regulator that it is possible to build. Figs. 6 and 7 represent the common system of transformer regulators. Mr. Ratcliff, referring to Fig. 7, mentioned that the regulating transformer C was placed on the low-tension side. This is quite a common practice because the regulating transformer is cheaper, is more efficient when wound for low voltage, and is also a more reliable piece of apparatus. I think that the method shown in Fig. 7 is the more reliable. Fig. 6 shows regulating tappings in the main transformer. Tappings are excellent and give a good degree of flexibility in the voltage, but the fewer tappings introduced in the main transformer the more reliable is the apparatus. All operating engineers will agree that, on this question of the type of voltage regulator, reliability is of paramount importance. Fig. 6 shows a type of regulating switch which I do not think is referred to in the text, viz. a regulating switch placed in the transformer. It is usually connected to the neutral end of the winding. This type of regulator has been developed recently in America and has already been applied, I understand, for feeders up to 66 000 volts, and for a fairly large output in kilovolt-amperes. I should like to ask the authors if they know of any of these switches in operation with the circuit alive. As far as I can gather, this type of switch has tappings on the neutral end of the transformer, operated by hand from outside, and can be operated only when the circuit is dead.

Mr. O. Howarth: The authors do not discuss the question of interconnected power stations with load tapped off the interconnector, or, what is practically the same, two stations interconnected at a point in the network of one of them. It does not seem to be a commercial proposition to transfer energy from one station to another and then back in the direction of the first station to the consumers, involving as it does extra copper, with consequent increased capital expenditure, and possibly extra copper losses when in operation. The station into which the interconnector is not carried will, of course, require to have some instrument which will indicate the load and power factor on the interconnector, and it would have been of interest if the authors had given particulars of any such instruments with which they are acquainted. If load is suddenly thrown on between two stations so connected, instead of the disturbance falling mainly on one station and so perhaps causing them to fall out of step, it will fall partly on each station, and less synchronizing power will therefore be required to maintain them in step. The conditions necessary for the satisfactory interconnection of power stations in the form of a ring have not been mentioned, and it seems to me that the difficulties of satisfactory operation in the case of a ring of stations such as shown in Fig. C will be very great. In the hypothetical case shown, the stations are connected as follows :—

Station A has an interconnector from the busbars to a point in the network of station B.
Station B has an interconnector from the busbars to a point in the network of station C.
Station C has an interconnector from the busbars to a point in the network of station D.
Station A has another interconnector from the busbars to a point in the network of station D.

The stations are assumed to be three-phase, receiving at 10 000 volts. Assuming that A is supplying 10 000 kW at 0·85 lagging power factor to B, and that the resistance between station busbars is 0·5 ohm per phase, the reactance voltage being equal to the resistance voltage, B will lag 0° 43′ behind A. Let the load which B supplies to C be 5 000 kW at 0·85 lagging power factor, and let the resistance between stations B and C be 1 ohm per phase, the reactance voltage again equalling the resistance voltage. Station C will lag another 0° 43′ behind B, i.e. a total of 1° 26′ behind A. Let A be supplying D with a load of 2 000 kW at 0·7 lagging power factor, and let the resistance between A and D be 1 ohm per phase, with the reactance voltage equal to the resistance voltage as before. D will then lead A by 0° 1′. The phase-difference between C and D is then 1° 27′ with D leading C, and, as this cannot be altered without disturbing the loading on the other stations, the power factor of the load between the two stations will be fixed for any given load. The relation of the power factor, load and voltage boosts are shown in Fig. F. It will be seen that it is impossible to close the interconnector switch without considerable disturbance. The minimum current is 103 amperes at 1 250 kW supplied to C by D, and closing the switch under these conditions, i.e. no voltage boost at either end, will disturb the loading of the other stations. If a boost of 250 volts is applied at C and the switch closed, 145 amperes will flow, but there will be no interchange of power, the line loss being supplied by one or both stations. Such an arrangement will obviously cause

considerable inconvenience in operation. In order to have full control of power factor and load it will be necessary not only to install a voltage booster but to have a booster which will alter the phase angle by adding voltages differing by, say, 90° from the busbar phase voltages, and it will also be necessary to provide this at any point where the ring might be closed, as obviously, if the systems are run by separate authorities

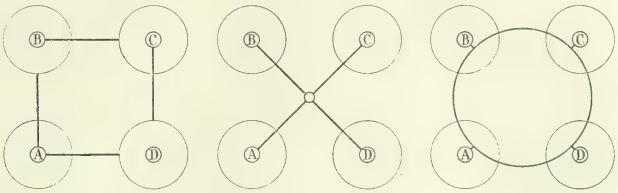


FIG. C. FIG. D. FIG. E.

who have agreements with each other as to the purchasing of electrical energy, they will not care to put extra copper into their systems and make the necessary alterations to their metering arrangements and agreements in order to cope with any disturbance which might be caused by the closing of the ring. The most satisfactory method of operating a number of stations in parallel will be to connect them "star," as shown

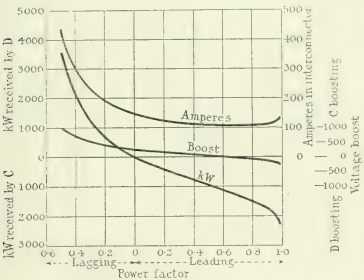


FIG. F.

in Fig. D, as each station can then control the load and power factor which it supplies into or receives from the common interconnector house without causing unexpected disturbance to the others. An alternative to this is shown in Fig. E, which is really the same as Fig. D with the busbars of the interconnector house pushed further out so that they form a ring main. Each station will then be able to control within limits the load and power factor which it supplies to or receives from the common ring, but it will not be able to determine which way round the ring the load will go. In such a system this will not, of course, matter any more than it does on an ordinary ring main. The objection to this system is the relatively high cost compared with the cost of that shown in Fig. C, and also the fact that it will not be so natural a growth as in Fig. C, which pictures a state of affairs which will grow naturally, due to undertakings making agreements to purchase in bulk from adjoining undertakings. The question of varying the price of electricity as the "weighted mean power factor" varies has been mentioned, and as the method of installing two single-phase watt-hour meters from the ratio of the readings of which the power factor is to be determined has also been referred to, I should like the authors to express their views on this method. In the following table the "weighted mean power factor" has been calculated for certain loads, and the figure obtained from the ratio of readings is also shown:—

Load			Kelvins			Mean equivalent power factor	
kW	P.F.	Period in hours	W_1	W_2	Total	Actual	From W_1/W_2
150	0·866 lag	8	400	1 600	2 000	0·72	0·693
50	0·5 lag	16					
150	0·866 lag	8	400	1 040	1 440	0·805	0·792
15	0·5 lag	16					
150	unity	8	1 400	2 200	3 600	0·911	0·933
150	0·866 lag	16					

It will be seen that the two are not necessarily the same, and taking the "weighted mean power factor" to be

$$\frac{\int \mathrm{kW} \cos\theta dt}{\text{Kelvins}} \text{ (where } t \text{ is in hours)}$$

it is obvious that the power factor obtained from the ratio of the watt-hour meter readings will not necessarily give the same figure.

Mr. L. H. A. Carr: The authors use the phrase "synchronizing power of the line," but I am of opinion

that there is only a de-synchronizing power. If 1 000 kW is thrown on suddenly at the receiving end of the line, and if the plant delivers 800 kW and the line feeds in 200 kW, I imagine that this 200 kW is what the authors have referred to as "synchronizing power of the line." I should be glad if they would confirm this view. The authors on page 294 refer to the oscillations produced in the line and discuss the magnitude of these oscillations, which they suggest are due to the strength of the original de-synchronizing power of the line. I do not see how that can be true. The oscillations must be due partly to the machines at each end of the line, and consequently those machines must exert an influence on the resulting oscillation. Does the line exert a damping influence on the oscillation, or not? One would imagine it is damped since the line has resistance. At the same time the machines themselves will of course provide a certain amount of damping. I would suggest that in their reply the authors should give some idea of how much the synchronizing power of the alternators is reduced by the line, because that is an important point.

Mr. D. S. Paxton: With regard to the question of the most economical power factor at which to transmit power from one system to another interlinked with it, it would appear, from a broad consideration of the question, that the best utilization factor for the whole plant will be obtained by an agreement that the transmitting station shall in general transmit at the power factor for which its generating plant is designed, with the reservation that if the power factor of its own system is at any time actually less than that for which the plant is designed, the operating engineer may have the option of informing the receiving station that power can be transmitted only at a rather higher power factor than usual but not exceeding unity. On the other hand, if the transmitting station habitually has a power factor higher than the figure for which it was designed (though I fear such cases will be few) an agreement may be made that the power transmitted through the interconnector shall be at a correspondingly lower power factor, which will bring the resultant power factor of the transmitting station to the value for which its plant is designed, thus fully utilizing the electrical portion of the machinery. In either event it may be accepted as an axiom that the transmitting station should be called upon to provide power only under conditions which do not unduly derange its own operation, and any additional wattless component required by the assisted system should be provided as far as possible at the receiving end of the line. Thus, if the receiving station is habitually loaded at a power factor below that of the transmitting station, it will probably be advisable to apply at the receiving station some artificial means of power-factor correction; whether by means of synchronous condensers, static condensers or, possibly, by over-excited synchronous induction motors on the station auxiliaries, etc., can be decided only in accordance with the special conditions in each case. Such artificial capacity or magnetization-current-producing plant should be dimensioned to provide the necessary wattless component to bring the resultant power factor, after receiving the supply through the interconnector on the agreed conditions, up to a value corresponding to the power factor for which the station is designed. In this way the generating plant in both stations will be utilized to the best advantage both in regard to kilowatt and kilovolt-ampere capacity; the interconnecting line can be designed for a power factor not widely deviating from unity, thus avoiding undue capital cost and/or copper losses; and artificial capacity only to cover the bare requirements of both stations need be installed. Where the direction of power transmission is reversible it may be advisable to install condensers or other such plant at both ends of the line, unless one of the stations works invariably at a higher power factor than the other, in which case it should be no hardship for the latter to transmit at the former's power factor. The foregoing remarks, as well as the paper itself, apply solely to station interconnecting links, but the future tendency will probably lie in interconnecting networks as opposed to central stations, as it certainly appears uneconomical to transmit power, say, 25 miles from one station to another and then to send it back perhaps $12\frac{1}{2}$ miles from the receiving station towards the transmitting station. The interconnection of networks would, however, entail financial amalgamation in a more or less complete degree, and this is not the subject at present under discussion. The question of a basis of payment for the transferred power does perhaps arise, however, and without any knowledge of what may have been arranged in any particular case I should like to suggest that both the kilowatt-hours and the kilovolt-ampere-hours should be metered, and the tariff based on a certain rate per unit with a surcharge of a fraction of this rate for the arithmetical difference between the two readings. This might equally be applied to power consumers, and would be more readily intelligible to them than cos ϕ calculations. It may be objected that no kilovolt-ampere-hour meter is available, but it is probably not beyond the wit of the meter manufacturer to evolve one. In view of the somewhat considerable trouble involved in synchronizing two independent stations, it is advisable that once established the link shall not be unnecessarily interrupted, and a reference to a method that has been devised to protect the alternators in such stations from the effects of short-circuits without disconnection from the line may be of interest. A short-circuit is dangerous to an alternator only as long as the machine is fully excited, and if the short-circuit is due to a flash-over, caused by a pressure surge or the like, a diminution of the voltage will probably extinguish the arc and clear the short-circuit. The system referred to consists in employing with each alternator, in addition to the usual automatic pressure regulator, a second similar regulator so connected that in the event of the maximum safe current for the alternator being exceeded, the excitation is reduced to a greater or less degree, until the fault clears itself or is cleared by switching out the feeders affected. Several traction stations, and others subjected to heavy short-circuits, have been protected in this manner, and have been in operation for considerable periods with satisfactory results.

Mr. C. M. Longbottom: In Fig. 1 it is pointed out

that if $IX = IR$, which we must accept, from the statement on page 293, as being the most suitable condition for the line, the mean angle of lead will be 45° which will give a mean power factor of 0·7. This, of course, will be very unsuitable. There is another point in Figs. 4 and 5, in regard to the question of regulators at either end of the line and one end only. This is chiefly an economic question. To have one regulator is, of course, much more desirable than to have two, for the reason that the loss in transmitting one way—at least the loss in the distant one—will have to be carried across the line; also the average voltage in the line will be lower, and therefore the cost of the line will be increased. The objection might be raised that in a reversal of power the conditions will be very unsatisfactory, as borne out by Fig. 5, but the question of over-voltage is not, I think, serious, and in certain cases where the transmitting back to the first station would be only of short duration the extra loss on the line would not be large. The reason why the power factor is not considered so seriously in America is that certain companies try to arrange that their districts are supplied at different times, with the result that the stations will not be operating under peak conditions at the same time. The question of power factor and wattless components does not, then, seriously affect the case.

Mr. J. Williams (*communicated*): With regard to formula (7) on page 295, I should like to ask the authors what is the greatest difference in power factor between the sending and receiving stations which they have experienced. A very large difference in power factor can be obtained when the receiving station is taking only a light load (say 10 per cent) compared with the capacity of the transformers, such load having a high power factor. This is due to the fact that the sending station has to supply the iron losses of the transformers at a low power factor, such losses being a high percentage of the total load in the case mentioned above. I give below the following references for the benefit of those who may desire to study this question still further:—

(1) J. W. Welsh: "Operation of Two A.C. Stations through Parallel Circuits, and the Distribution of Load and Wattless Current between them." *Proceedings of the American Institute of Electrical Engineers*, April 18, 1912.

(2) H. W. Smith: "Interconnection of Power Systems." *Electric Journal*, 1920, vol. 17, p. 515.

(3) R. Bailey: "Voltage and Power Factor Control of 66 000-volt Transmission Lines connecting Two Generating Stations." *Journal of the American Institute of Electrical Engineers*, 1921, vol. 40, p. 462.

Messrs. L. Romero and **J. B. Palmer** (*in reply*): This paper was intended to be a sequel to Mr. Peck's 1916 paper, and it is therefore a source of satisfaction to us to find that Mr. Peck is generally in agreement with it. We agree that it would have added to the value of the paper if we had given definite examples of the working out of the formulæ, and we set out below the calculations for col. 1 of Table 1. It is of course quite simple, as Mr. Peck explains, to read the voltages and power factors directly from a Mershon chart fairly accurately, but we venture to think that the calculations from the formulæ are even simpler. If one had a number of these interconnector determinations to make, and great accuracy were not required, it would probably pay to have a large-scale Mershon chart as a permanent fixture in the office, but if a chart were not available a considerable number of accurate results could be obtained by calculation in the time taken to prepare the chart. Once available, however, we agree that all interconnector problems could be solved very quickly by it. It is true that we have attempted to deal only with short lines in which the capacity current is practically negligible. The calculation of long high-voltage lines is complicated by the capacity current and is quite a problem by itself. For accuracy it would be necessary to take into account also the watt and wattless components of the leakage represented by the exciting current of the transformers; the wattless component when expressed as an "admittance" being arithmetically subtractive from the capacity susceptance of the line. Dealing with the matter broadly, the effect of capacity in a line is to reduce the reactance and the resistance-drops, and this, for an example we have investigated, would (for a 0·9 power factor lagging load) have the effect of reducing the amount of boost required at full load, and of increasing slightly the phase-displacement between the sending and receiving voltages. The power factor at the sending end would, however, be improved.

Example showing the calculation of col. 1, *Table* 1. *Data.*

Station B is to receive 10 000 kW at 0·7 power factor lagging from station A.

Busbar voltage at stations A and B, 6 600, three-phase, 50 periods. Transformer capacity at each end, 15 000 kVA. Copper loss of each transformer at full load (90° C.), 161 kW. Reactance at full load, 4·85 per cent. Voltage ratio 6 600/33 000 at no load.

One cable 0·2 sq. inch, 16 miles long, 33 000 volts; resistance, 0·256 ohm per conductor at 60° C.; inductance, 0·52 millihenry per mile.

Resistance per phase (cable)

$$= 0{\cdot}256 \times 16 = 4{\cdot}1 \text{ ohms}$$

Equivalent resistance per phase (transformers)

$$= \frac{2 \times 161}{15\,000^2} \cdot \frac{33\,000^2}{10^3} = 1{\cdot}56 \text{ ohms}$$

Total resistance per conductor, R, is therefore 5·66 ohms.

Reactance per phase (cable)

$$= \frac{2\pi 50}{1\,000} \cdot 16 \cdot 0{\cdot}52 = 2{\cdot}6 \text{ ohms}$$

Reactance per phase (transformers)

$$= \frac{2 \times 4{\cdot}85 \times 33\,000^2}{15\,000 \times 10^5} = 7{\cdot}0 \text{ ohms}$$

Total reactance per conductor, X, is therefore 9·6 ohms.

The current in the line, $I = \dfrac{\text{kW}_1 \times 1\,000}{3E_1 \times \cos\phi_1}$

$$= \frac{10\,000 \times 1\,000}{3 \times 19\,052 \times 0{\cdot}7} = 250 \text{ amperes}$$

Whence $IR = 250 \times 5{\cdot}66 = 1\,415$ volts
and $IX = 250 \times 9{\cdot}6 = 2\,400$ volts.

The voltage to be added by the booster, in terms of the extra-high-pressure, is :—

$3(E_2 - E_1)$. (*Note that E_2 and E_1 are voltages to neutral.*)

$$E_2 = \sqrt{[(E_1 \cos\phi_1 + IR)^2 + (E_1 \sin\phi_1 + IX)^2]}$$
$$= \sqrt{[(19\,052 \times 0{\cdot}7 + 1\,415)^2 + (19\,052 \times 0{\cdot}714 + 2\,400)^2]}$$
$$= \sqrt{(14\,753^2 + 16\,005^2)}$$
$$= 21\,761$$

The voltage added by the booster is therefore

$$\sqrt{3}\,(21\,761 - 19\,052)$$
$$= 4\,680 \text{ volts (in terms of the E.H.P.)}$$

The booster capacity is $3I(E_2 - E_1)$ volt-amperes

$$= 3 \times 250\,(21\,761 - 19\,052)$$
$$= 2\,030 \text{ kVA}$$

Now let us consider the power factor at the sending end ($\cos\phi_2$).

$$\phi_2 = \text{arc tan}\,\frac{E_1 \sin\phi_1 + IX}{E_1 \cos\phi_1 + IR}$$
$$= \frac{16\,005}{14\,753}$$
$$= \tan 47^\circ\,19'$$

Therefore $\cos\phi_2 = 0{\cdot}678$

The kVA at the sending end $= \dfrac{3IE_2}{16\,300} = 1\,000$

The kW at the sending end $= 16\,300 \times 0{\cdot}678 = 11\,060$.
The kW at the receiving end $= 10\,000$.
Therefore the loss in transmission is $1\,060$ kW.

It will often be necessary to determine what the power factor of transmission would be with a given boost, for a given value of kVA transmitted.

Example : What would be the power factor of transmission in the line illustrated in the previous example if the load at the sending end of the interconnector were 16 300 kVA, and the voltage applied to the primary of the step-up transformer 7 536 ?

$$E_2 = \frac{7\,536 \times 33\,000}{6\,600 \times \sqrt{3}} = 21\,761 \text{ volts}$$

$$I = \frac{16\,300 \times 1\,000}{3 \times 21\,761} = 250 \text{ amperes}$$

$IR = 250 \times 5{\cdot}66 = 1\,415$ volts (as before)
$IX = 250 \times 9{\cdot}6 = 2\,400$ volts (as before)

As $E_2 - E_1 = 21\,761 - 19\,052 = 2\,709$ volts is greater than IR the power factor ($\cos\phi_2$) will be lagging,

therefore $\phi_2 = \alpha - \epsilon_2$

$$\tan\alpha = \frac{IX}{IR} = \frac{2\,400}{1\,415} = \tan 59^\circ\,30'$$

$$IZ = \sqrt{(IR^2 + IX^2)} = \sqrt{(1\,415^2 + 2\,400^2)} = 2\,786$$

$$\cos\epsilon_2 = \frac{E_2^2 - IZ^2 - E_1^2}{2E_2 \times IZ}$$
$$= \frac{21\,761^2 + 2\,786^2 - 19\,052^2}{2 \times 21\,761 \times 2\,786}$$
$$= 0{\cdot}975$$
$$= \cos 12^\circ\,36'$$

$$\phi_2 = \alpha - \epsilon_2$$
$$= 59^\circ\,30' - 12^\circ\,36'$$
$$= 46^\circ\,54'$$

Therefore power factor $= \cos 46^\circ\,54'$
$= 0{\cdot}68$ (approximately)

Following Mr. Peck's suggestion we give below the calculations for the synchronizing power for variations of phase angle of 1° and 10° based on the conditions in col. 1, Table 1, calculated from formula (13) in Appendix II.

$X = 9{\cdot}6$ ohms. $Z = 11{\cdot}14$ ohms.
E_1 and $E_2 = 33\,000/\sqrt{3}$. $\beta = 1^\circ\,42'$.
When $\theta = 1^\circ$, synchronizing power $= 1\,464$ kW.
When $\theta = 10^\circ$, synchronizing power $= 14\,571$ kW.

We are of opinion that the synchronizing power of this line would be adequate for all ordinary conditions of working. The synchronizing power of interconnecting lines will obviously decrease as their carrying capacity in kVA decreases and as their length increases, and it is probable that the synchronizing power of a line of the same length but only 1/10th of the capacity of that worked out above would not be adequate except for very steady load conditions.

We are in substantial agreement with most of Mr. Ratcliff's remarks, but we cannot accept his suggested improvement for Fig. 1 in the paper. The practical problem to be considered is the effect on the power factors at the two ends of the line of varying the boost for a fixed load in kilowatts delivered to the receiving station. Under these conditions the line voltage triangle (showing resistance, reactance and impedance-drops) will grow in size as the boost varies from the value necessary for unity-power-factor transmission, owing to the increase in current as the power factor varies from unity in either direction, and the effect of this increase in current is to make the variations in power factor much less than those shown by Mr. Ratcliff. His assumption is correct only for a fixed current transmitted and, as this is a purely artificial condition, it is liable to obscure the problem, as is also his deduction from it as to the maximum value of the boost.

It would be difficult to compare the arrangements of step-by-step regulators shown in Figs. 6 and 7 on a cost and efficiency basis, as the methods have different fields of application. It is clear, however, that the arrangement shown in Fig. 6 requires less apparatus than that shown in Fig. 7, but the limitation imposed by the

voltage of the circuit would often prevent the use of the former arrangement. Mr. Ratcliff questions our statement on page 292, and says that any supply undertaking would endeavour to induce a consumer to improve a power factor as low as 0·7, if possible. We feel that the only effective way of inducing consumers to improve their power factor is by giving them a financial interest in the improvement, and we are therefore of opinion that, whenever practicable, alternating-current supplies should be charged for on a power-factor basis. We agree that the two single-phase watt-hour-meter method of determining the power factor is probably the fairest and most satisfactory for ordinary consumers' supplies, but we are not so clear that it is the ideal method for use on power station interconnections.

Mr. Ellis raises an important point in mentioning the case where three or more stations are interconnected through a ring main. As he says, it is quite possible for two of the stations to find themselves unable to complete the interconnection owing to the phase angle introduced by transformer connections; for instance, the delta/star connection, which would require the stations to have a permanent minimum phase angle of 30 degrees at no load, if there were one delta/star bank in the interconnector. The phase angle introduced by transformers must not be confused with the difference in power factor which exists between the ends of an interconnector and which is caused wholly by the impedance of the line. The example Mr. Ellis gives, in which, in effect, two stations are interconnected by lines having widely different impedances, is an interesting one, and it is possible to get surprisingly large currents circulating. The remedy, as Mr. Ellis suggests, is to boost both interconnectors separately, and in some cases it would probably be necessary to equalize the impedances of the parallel circuits artificially. We agree with Mr. Ellis that it is generally undesirable to introduce a number of tappings into large high-voltage transformers. In America the tapping switch, capable of changing tappings under load, is used to some extent in distribution transformers, but, as far as we are aware, has not yet been applied to transformers feeding transmission lines. Some of the supply undertakings, however, appear to be calling for this development, and it is probable that the demand will be met in the near future.

In reply to Mr. Johnson, the position of the electricity supply industry in the United States is very different from that of the British industry. The interconnection of the supply undertakings' networks certainly has had a beneficial effect on the load factor, but the principal causes of the high load factors are the diversity of industry, the extent to which the railways are electrically operated, and (in California) the irrigation load. We have no information as to graded tariffs, but it is a fact that the use of electricity is very much more general than it is here, which goes to show that the supply is relatively cheap and abundant. The prospect of interconnecting undertakings whose load curves are the inverse of each other is very attractive, but the condition probably does not exist within the economical limits of transmission.

Mr. Coates and other speakers have questioned the statement in the paper that contactor-type and face-plate type regulators are limited to about 3 000 volts. As Mr. Coates mentions, there are no technical reasons why higher-voltage apparatus should not be constructed and, as a matter of fact, since the paper was written several have been installed.

Mr. Collinge's interesting account of his experience with interconnected systems does not call for reply.

Mr. Howarth raises the question of load tapped off the interconnector, and we would refer him to our reply to the discussion in London on this point. In reply to his question about instruments to be located at one power station to indicate the load and power factor of the supply fed into its network by another power station, we would refer him to a recent article in the *Electrical Review* by Mr. Fawssett of the Newcastle Electric Supply Company, describing an ingenious method which he has devised for making these measurements. We think that it would be difficult and inadvisable to run Mr. Howarth's four power stations as either a closed or an open ring, unless the loads delivered by each station, and the power factors, were under the control of one man. The open ring would be easier to operate, but it might be less economical in copper and losses. In a closed ring or in any other kind of parallel connection the loads on the power stations are governed entirely by the power supplied to the prime movers without regard to the electrical conditions, and in Mr. Howarth's example, as all the stations are already running in parallel, the closing of the ring between stations C and D would not appreciably alter the loads carried by the several stations, but it would certainly alter the power factors owing to the alteration in the distribution of the loads between the various interconnectors. We could not say what the distribution of the loads would be with the ring closed, without having full data of the loads on the networks, etc., but it is obvious that the power factors in the interconnectors would readjust themselves to the loads they would have to carry and to the electrical conditions in the whole ring, and the currents might be lagging in some of the interconnectors and leading in others. We agree with Mr. Howarth that in such a closed ring it would be impossible to adjust independently all the loads and power factors in the ring, as the conditions in the ring as a whole would obviously have to balance.

Mr. Howarth puts forward a star arrangement of interconnection as more satisfactory from the operating point of view than a ring, and states that under this arrangement each station could control the load and power factor which it supplies to or receives from the ring. We disagree with him here, as it seems clear that one station could increase or decrease its load only at the expense of the others, and confusion might result if the load distribution and power factor control were not under one man. The same criticism applies to the arrangement shown in Fig. 4.

Mr. Howarth proves clearly that the definition of the power factor given by the two watt-hour-meter method as " a mean value which is weighted in proportion to the extent and duration of the load " is not strictly correct.

In reply to Mr. Carr it may be as well to say at once

that when we refer to the "synchronizing power of the line," the word "power" is used in its engineering sense and not in its general sense of "influence." The 200 kW to which Mr. Carr refers is load power and not synchronizing power, and we would refer him to the definition given in the paper and in our reply to the discussion in London. Mr. Carr starts off with the idea of two machines running in parallel and states that if a transmission line be inserted between them the effect of the line is a de-synchronizing one. This is correct, but is not the problem under consideration. We would remind Mr. Carr that the two machines are in reality running in two separate power stations; that the introduction of a transmission line between them is for the purpose of enabling them to be run in parallel; and that its effect is therefore to increase the synchronizing power which will flow between them from zero to something quite considerable. We believe that if Mr. Carr had not started with the idea of separating two generators in one power station by means of a transmission line he would not have found fault with the use of the expression "synchronizing power."

The statement on page 294 which Mr. Carr challenges was put forward tentatively, but further consideration has confirmed our opinion that it is substantially correct. We did not suggest that the magnitude of the oscillation through the line was independent of the type and design of generator plant running in the two power stations, but that, given machines of the same type and design, it was independent of the capacity of the plant running. We agree that the line will have a damping effect on the oscillations. The statement on page 293 with regard to synchronizing power which is challenged by Mr. Carr appears to us to be quite clear and correct, but in order to satisfy Mr. Carr it might be stated alternatively as follows: "For all values of E_1, E_2 and β, and for any given value of resistance the synchronizing power is a maximum when the reactance of the line is equal to the resistance of the line."

Mr. Paxton has summed up the effects of power-factor variation very ably indeed, and the conclusions he arrives at in regard to the equitable division of the wattless component are quite sound in the conditions we have considered, namely, the case of the interconnection of two or more independent self-contained undertakings. It is possible, however, that a joint electricity authority, having autocratic powers over a number of stations, might find it more economical and convenient to run the most efficient stations at the highest possible power factors, as some of the hydro-electric companies do in America, but every case would have to be considered on its merits. Mr. Paxton's remarks, and the paper itself, deal mainly with the interconnection of stations, which is often the only feasible method of interconnecting systems, but we agree that the interconnection of networks is often possible and in many cases would be more effective and less costly than the interconnection of station busbars. The reduction of generator excitation either automatically or by hand on the occurrence of a fault, is common practice in America, and in the case of overhead transmission lines there can be little or no objection to it, since the majority of faults are insulator flash-overs which, when the arc has broken, generally leave the line unimpaired and fit for service. This method would probably not be effective on an underground cable system, on which a fault usually puts a cable out of commission until it can be repaired.

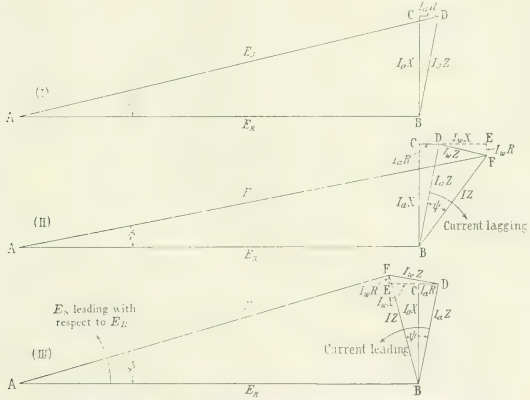
In reply to Mr. Longbottom, we said on page 293 that for a given resistance of line the synchronizing power is a maximum when the reactance of the line is equal to the resistance, but we do not suggest that this relationship is the most suitable for the transmission of power with station voltages constant and equal. On the contrary, we indicate that the mean power factor of transmission might be fairly near unity if the value of X were made as large as would be safe from the point of view of synchronizing power. We agree that if satisfactory operation can be obtained with a regulator at one end of the line only, there is very little to be gained by installing regulators at both ends, but the case illustrated in Fig. 5 shows that in many cases two regulators would be necessary. It is not entirely a question of extra loss in the line, as Mr. Longbottom suggests, as shown in Fig. 5; when the flow of power is towards the station having the regulator there would either be some loss of power-factor control or the busbar voltage at the receiver station would have to be lowered.

Mr. Williams raises the point of the large difference in power factor which may obtain between the two ends of the interconnecting line when it is transmitting only a small percentage of its full load. This point, although interesting, is not of much practical importance, as a low power factor at light loads is not troublesome and does not add appreciably to the cost of transmission. Where transformers are employed in the line this would arise, as Mr. Williams points out, from the effect of the wattless component of the magnetizing currents of the transformers which, being a fixed quantity, becomes relatively important when the load through the line is small, and makes the power factor at the sending end lag behind the power factor at the receiving end by an amount greater than would be given by formula (7) on page 295. We would point out, however, that this effect is produced by the difference in value and phase angle of the currents at the two ends of the line and not to any increase in the phase angle between the station voltages, which on the contrary is slightly reduced. A similar effect would be produced by consumers with low, lagging power factors being tapped off the line. Capacity in the line would have the opposite effect of reducing the difference in power factor between the two ends of the line. We have dealt with the general effect of line capacity in replying to Mr. Peck.

NORTH MIDLAND CENTRE, AT LEEDS, 14 MARCH, 1922.

Mr. G. A. Juhlin : The questions dealt with by the authors are extremely interesting and of considerable value. The authors state on page 288 that without the provision of a regulator the sudden making or breaking of the large wattless current which would flow at no load would have serious effects on the busbar pressures at one or both stations. It seems to me that even with the voltage regulator in use there will be a considerable variation in voltage if the load should suddenly be reduced at the receiving station, due to the fact that the drop in the interconnector will change materially and, while this drop will to a certain extent be reduced by the changes in the wattless current, it may in some cases be quite considerable. I should like to have the opinion of the authors on this point. The figures given in the paper for obtaining the relation of the voltage vectors with varying power factors of the load to be transmitted over the interconnector will solve most of the problems but will not give a solution when a booster is not in use. I believe that under these conditions the problem is indeterminate unless the current is split up into its components of useful current and wattless current. If this method is adopted, an accurate and easy solution of the problems under any conditions is possible. Fig. G shows the diagrams of electromotive forces for different conditions as regards wattless current. The following symbols are used : I_a = load current ; I_w = wattless current ; X = total reactance of interconnector (including transformers) ; R = total resistance of interconnector ; and Z = total impedance of interconnector.

Fig. G (I) shows the relation between the E.M.F.'s when power is transmitted at unity power factor. AB is the E.M.F. at the delivery end of the interconnector ; BC denotes the E.M.F. due to the load current I_aX and displaced 90° from E_R ; CD is equal to I_aR or the ohmic drop due to the load current, and is of course in phase with E_R. AD then represents the E.M.F. E_S required at the sending end of the interconnector. If the power factor of the load to be transmitted varies from unity, the relation between E_S and E_R is somewhat more complex, on account of the wattless current. Fig. G (II) represents the E.M.F.'s when load having a lagging power factor is transmitted. AB is, as before, the voltage at the receiving end ;



(I) Unity power factor (II) Lagging power factor (III) Leading power factor

FIG. G.

$BC = I_aX$, the E.M.F. due to the load current through the reactance, and $CD = I_aR$, the E.M.F. due to the ohmic drop of the load current. BD is then the impedance drop due to the load current and is equal to I_aZ. Referring to the E.M.F.'s due to the wattless current I_w, the value of this current is readily obtainable as it is fixed by the power factor of the load to be transmitted. It is clear that the impedance E.M.F. due to this current must be at right angles to I_aZ. It consists of two components, I_wX and I_wR. I_wX is in (time) phase with ER, while I_wR is displaced 90° from I_wX. The E.M.F. I_wZ due to the wattless current flowing through the impedance is then represented by DF, and the E.M.F. due to the total current flowing through the impedance by the line BF,* and from this value the

* The E.M.F. required at the sending end of the interconnector is then equal to AF.

amount of boost required may be obtained. Fig. G (III) shows the diagram when the power transmitted has a leading power factor. Considering the problem of transmitting a certain amount of power over the interconnector,* the solution may be obtained by drawing the diagram exactly as in Fig. G (II), except that the line DF representing the E.M.F. of the wattless current I_w through the impedance Z will be on the left-hand side of the line I_aZ, instead of on the right-hand side as in the previous diagram. Now as there is no boost the voltage at the sending end must be equal to that of the receiving end. Consequently E_S is known. I_wZ may then be obtained by taking A as a centre of a circle with radius E_S and striking an arc intersecting a line at right angles to BD. The wattless current required is, of course, obtained by dividing the E.M.F. by the impedance. The power factor of transmission may now readily be obtained from the diagram by the angles ψ and ϕ. It should be remembered that the current is lagging when I_wZ lies on the right-hand side of BD, and leading when on the left-hand side, and that the E.M.F. E_S leads E_R when it lies above the latter, and lags when below. Taking the plus sign as indicating leading, and minus for lagging power factor, the power factor of transmission is denoted by the expression $\cos(\psi + \phi)$. Having obtained the power factor of transmission, it is a simple matter to calculate the power factor of either sending or receiving station from the load conditions of the respective stations. I have checked the figures given in the table shown by the authors, and obtained the power factors within $\frac{1}{2}$ per cent, which is sufficiently close for practical purposes.

Mr. P. Furness : The American practice appears to be to charge for current on two different scales—regulated and unregulated. Can the authors tell us what the difference is in price for the regulated supply as compared with the unregulated supply ? Is it the custom in America to tap the interconnector for individual consumers ? Voltage regulation would not have to be a very important consideration to a consumer connected to an interconnector. Referring again to the unregulated supply, what regulation is commercially necessary in practice ?

Mr. R. M. Longman : Fig. 1 is very interesting, and will be of great assistance to engineers considering this question. It shows at once that in the case of stations with equal voltages we can transmit power at only one power factor, but the power factor of the load transmitted depends on the ratio of resistance to reactance of the interconnecting line or cables. It is at once evident that if we wish to improve the power factor of the transmitted load the resistance must be diminished. I should like to know whether the formula for synchronizing power on page 293 includes the reactance of the generators. Also, can the authors give us some particulars as regards the reactance, resistance and capacity of some of the American transmission lines—although the actual conditions of America are not likely to be repeated here ? On the interconnection of two stations in this district about 15 miles apart in which the smaller station has more load on its network than it can usually deal with, a bank of transformers has been used as auto-transformers—the incoming interconnectors have been connected to the lowest tapping and the busbars to the highest tapping of the same winding, thus obtaining a boost of about 10 per cent. This has been of considerable value while larger sets were being installed, and has saved the expense of a regulator. The question of synchronizing power becomes of importance when the smaller sets are being replaced by larger ones. I once witnessed a good example of phase-swinging between two stations, many miles apart, which were normally connected through two lines—one having more copper and load capacity than the other. The systems were paralleled only through the smaller line, and as conditions were unstable the synchroscope was plugged in preparatory to closing up on the other line. The synchroscope pointer started swinging through a repeatedly increasing arc and finally had swung completely round, indicating that the other interconnecting switch had opened. One of the chief causes of hunting or phase-swinging is in the prime mover, and may be due to the governor of a turbine set. Cases have been known of stations operating in parallel and considerable hunting taking place ; this has been traced to the governor of a particular machine, and on this being taken off the trouble ceased. The switching-out of part of the interconnecting feeders between two systems has also been seen to cause phase-swinging, and on closing the switch more stable conditions have immediately resulted ; this is generally due to an increase in the amount of copper in the interconnection. The authors have mentioned the case of two regulators —one at each end of the line—as theoretically giving the best results, but that should not be allowed unless it is clearly understood that the operation of these regulators is under the control of one authority. Referring to the use of induction regulators for voltages of 11 000, I feel rather dubious about the advisability of using on this voltage movable flexible connections such as would be required for the rotor portion. One method of overcoming this difficulty would be to put the series windings of the regulator on the stator, and to use a transformer to step down the voltage for the rotor. A standard transformer could be used for this purpose, and the shunt winding could be for a voltage of 2 000 or even less. I do not know whether this method has been tried, but in any case I should like to know the authors' opinion regarding the advisability of using induction regulators at 11 000 volts, and whether the experience of their use in the States has been satisfactory. With further reference to the interconnection of two stations in which load has always to be transmitted in one direction, Fig. H has been made out for two particular stations showing, for a given load on the network of the smaller station, the amount of load in kilovolt-amperes and its power factor which the generators have to supply for varying amounts of power transmitted by the interconnectors at different power factors, the power factor of the network load being assumed to be 0·8. The method of using the diagram is as follows : For a given load supplied by the interconnector, say 20 per cent at a power factor of 0·9

* Without the use of a booster.

(lead), look along the 20 per cent line and where this cuts the 0·9 (lead) full line read off the value on the left-hand ordinate—in this case 92·3 per cent. Also see where the 20 per cent line cuts the 0·9 (lead) dotted curve and read off the value on the right-hand ordinate —in this case 0·67 (lag). This means that with 20 per cent of the network load transmitted by the interconnectors at 0·9 (lead) power factor the station in question has to generate 92·3 per cent load at a power factor of 0·67 (lag). A curve like this should, of course, be used in conjunction with another curve showing the voltage-drop on the interconnecting lines at the ments is delivered into the Power Company's mains. It is not possible, however, during the dinner hour to keep the load to 1 000 kW, as the local load has fallen off and the amount of power delivered into the Company's mains is limited by the large wattless current which would trip the circuit breaker between the two systems. This is partly obviated by generating current at about 0·9 power factor, which reduces the wattless current supplied into the Company's mains ; at the same time, however, the pressure rises, but this is not very disturbing at that period of the day. With the exception of some surges and two or three cases of severe oscilla-

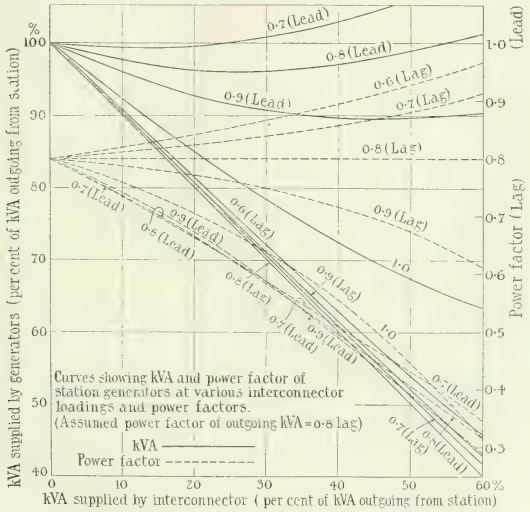


Fig. H.

different power factors, and the two together should be of considerable assistance to a load despatcher.

Mr. S. D. Jones : This paper deals chiefly with large stations delivering power to one another. My case is that of a comparatively small station running in parallel with the Yorkshire Power Co.'s system. The bulk of our supply is direct current, and is a tramway, lighting and power load. We have also a growing alternating-current load. We have now been running in parallel with the Power Company's system for over a year and, on the whole, we have had little difficulty. The load is a steady one of 1 000 kW during the day, the steam plant being shut down during the night and at week-ends, the supply then being taken from the Company. Any excess load above local requirements apparently caused by heavy fluctuations of load on the Company's system, the running has been very satisfactory, and it is pleasing to know that on one or two occasions the small station has been able to render slight assistance to the large one.

Mr. C. A. Gillin : I think that I am not going beyond the scope of the paper in considering the case of several stations electrically interconnected but individually under the managerial control of the present undertakers. That is the position likely to result in some of the districts already delimited by the Electricity Commissioners. Unity of operation-control is shown in this paper to be absolutely necessary ; and the allocation of wattless current and its cost is a matter which may or may not be satisfactorily settled between the parties concerned.

The question as to how this control should be effected is another matter, and the authors appear to have had in view only the interchange of power on a comparatively small scale between two stations. Cases will arise in the near future when the interchange of power will range from small amounts up to 50 000 kVA or more. This means that several comparatively large cables, with their corresponding transformers, will be in parallel at high voltages, and, as the ratio of the reactance to the resistance will be high, no difficulties should arise in regard to the synchronizing capacity of the interconnecting lines. I agree with the authors that condition 3(*b*) referred to on page 289 will be essential for satisfactory control under these conditions, but I should like to have their views as to the number, size, and type of regulators to handle loads up to 50 000 kVA divided between 3, 4 or 5 large cables. Would they suggest stub busbars and one regulator; or one regulator per feeder with the transformer as part of the feeder unit; and, if the latter, should not the regulators be electrically interconnected? I should imagine that with these arrangements the electrical interconnection of the regulators would be extremely expensive, if not prohibitive. It appears to me that as there is at present absolutely no experience to guide one in these matters, it will be advisable to do the job first and tackle the troubles as they arise.

Messrs. L. Romero and **J. B. Palmer** (*in reply*): We agree with Mr. Juhlin that there would quite possibly be a considerable variation in voltage if the load were suddenly reduced at the receiver station, but it would be possible to adjust the voltage quickly if a regulator were installed. Our point is, however, that when condition (2) prevails, i.e. when a permanent "boost" is given to the interconnector, it is necessary to provide some means of adjusting the voltage difference to approximately zero before switching in and, while, of course, sudden variations in load will generally cause variations in voltage, we think that voltage conditions are more likely to be improved by the provision of regulating apparatus. The effect mentioned by Mr. Juhlin is an abnormal condition, whereas our statement refers to normal working.

Mr. Juhlin's diagram for determining the relationship of the voltage vectors in the interconnecter system is most interesting. We have compared the working out of a number of problems by the formulæ given in the appendix, with results obtained by Mr. Juhlin's graphical method, and find the latter to be reasonably accurate. For cases where the receiver power factor is known we find the use of our formulæ to be the simpler method, but in those cases where the receiver power factor is unknown, these including practically all the leading-power-factor conditions, Mr. Juhlin's method is undoubtedly more simple and satisfactory than the rather cumbersome trial-and-error calculations from the formulæ, and we consider Mr. Juhlin's contribution to the discussion to be very useful.

In reply to Mr. Furness, we are unable to say if it is general practice in the United States for the power companies to charge on two different scales for regulated and unregulated supply. The authors know of one case where this is done, but they have no information as to the difference in price. The amount of regulation required is not very large in the majority of cases, considering all the factors attending long-distance transmission which tend towards poor regulation, and in general does not exceed 10 per cent.

In reply to Mr. Longman, the formulæ for synchronizing power do not include the reactance of the generators; by definition the symbols E_1 and E_2 are the voltages at the end of the interconnecting cable. The point has already been dealt with in our replies to previous discussions. The reactance, resistance and capacity of transmission lines depend on a number of variables, e.g. length, size of wire and spacing, which in turn vary according to the voltage and total power to be carried. It would therefore be very difficult for us to give Mr. Longman any figures for the reactance, etc., of American transmission lines, except for a specific case.

We agree that the installation of regulators at both ends of a line would be likely to lead to difficulties if there was not a definite understanding at all times as to which station was responsible for the voltage control. With regard to induction regulators we agree that there will undoubtedly be cases where the size of the regulator or other circumstances might make it desirable to supply the rotor at a moderate voltage from a step-down transformer, but we think that there is no ground for apprehension in connecting induction regulator rotors direct on to the lines at 11 000 volts, and experience in the United States and elsewhere corroborates this view. The curves shown in Mr. Longman's diagram should be useful to the station staff, and could probably be constructed for any particular system for values of kVA or amperes instead of percentages of the total kVA load on the station.

Mr. Jones's experience of interconnection with the Yorkshire Electric Power Company is interesting. It goes to show that a small undertaking can be successfully run in parallel with a large one. We gather that the voltage and power-factor variations inseparable from interconnection without regulating apparatus are within the limits with which Mr. Jones is able to deal.

Mr. Gillin's questions, in so far as they apply to a general case, are difficult to answer. If an interconnection of 50 000 kVA or more were contemplated it would be necessary to take a number of factors into consideration. It is possible that a station of this capacity would be a new station delivering the whole of its output at one point, in which case there might be no objection to the busbar voltage being maintained at such a value as to give the maximum economy in transmission losses. A station of this capacity would possibly also be run as a high-load-factor station, in which case a permanent boost given by transformer ratio would probably be adequate to deal with the normal voltage requirements. If, however, the circumstances were such that only a portion of the outgoing feeders from a station had to be regulated, it would be quite possible to operate two or more regulators simultaneously from one controller. The "stub" busbar system suggested by Mr. Gillin would be worth consideration, but for interconnections of the size he is

considering it would rarely be possible to effect all the adjustment by one regulator. We do not think it is possible to make a definite recommendation as to the best way of regulating very large interconnections, since there are so many variables, but we should be inclined to give full consideration to the synchronous condenser in these special circumstances, and we can imagine cases where it should be possible to transfer large blocks of power without employing any regulating apparatus at all.

Liverpool Sub-Centre, at Liverpool, 20 March, 1922.

Mr. J. A. Morton : The literature of this subject, in this country at any rate, is rather scarce, although a certain amount has been published in the United States. The problems in America are, however, rather different from those we have to consider here, as the distances are greater and the interconnections are made by overhead lines and not by cables, as is more often the case in England. The parallel operation of two power stations is similar to the running in parallel of two generators on the same busbars, the only difference being the impedance of the cable connecting the two stations, and one looks upon the cable as merely a reactance like that between two sections of busbar in the same station. At first sight it seems as though all one had to do to get the power to flow through it would be to raise the voltage at one end ; but in practice it is not so simple. The authors point out that the division of the load depends entirely upon the supply of energy to the prime movers and not upon the voltage adjustment. A difference in pressure between the two ends of the interconnector will not cause a transference of power through the cable, unless there is power available I wish to refer chiefly to the figures given in Tables 1 and 2. In col. 1 the size of the booster is given as 2 320 kVA ; this seems to be too large. With regard to Table 2, the comparisons are based on a 0·2 sq. in. cable, which will just carry the load, but it does not necessarily follow that this is the most economical size. In fact, it will be found that a 0·25 sq. in. cable would be more economical than a 0·2 sq. in. cable, because a considerable portion of the cable capital charges are for laying and jointing, and street work, and are constant for any size of cable. A 0·25 sq. in. cable would increase the capital charge by only about 10 per cent, but the energy loss in the cable would be reduced by 20 per cent. I merely mention this, not because it makes any difference to the authors' comparisons, but to show that the problem of the best size of interconnector is a separate problem inside the main problem. If a 0·25 sq. in. cable had been taken, the total costs of transmission would have been slightly reduced. In the authors' formulæ the capacity current is ignored, but I thought it would be interesting in this particular case to see what difference the capacity current would make. The capacity current in the 16 miles of cable is about 35 amperes (total), and when this is taken into account we get a smaller resultant current in the interconnector, a reduced loss, and a higher power factor of the current in the cable. It seems to me that a booster 10 or 12 per cent smaller can be used if the capacity current is taken into account in this particular instance. This is a point that might be worth looking into, particularly with a longer line. If the load were 5 000 kW instead of 10 000 kW the capacity current would make a much greater difference, because it would remain practically constant, while the load current would be halved and would thus have a proportionately bigger effect. On page 293 the ratio of reactance to resistance is given as 1 : 1. In a paper read by Mr. Wedmore some time ago the relationship was given as 2 : 1 as being reasonable between the machines, i.e. in the interconnector. I think that in the discussion which followed it was suggested that this ratio included the machine reactance as well as the reactance in the connecting link. The question arises as to whether the machine reactance should be taken into account in considering the 1 : 1 ratio proposed by the authors. We might take the case of a 6 600-volt interconnector, where there are no transformers in the circuit. If an underground cable were used, it would have very little reactance in itself, but if we assume the usual 10 per cent generator reactance and include this at one end of the cable we can go up to about 10 miles without inserting any extraneous reactance in the cable. If, however, the generator reactance is left out of account we should have to insert an extraneous reactance of about 10 per cent in such an interconnector, as a working necessity for the purposes indicated in the paper. Probably we should insert such a reactance in any case for safety. If the tie line between these two stations were not a cable but an overhead line, its inherent reactance, which is about 4 times as much as in a cable, would be sufficient so far as reactance is considered as a working necessity. As an alternative to varying the voltage, the impedance of the line could be varied by altering an extraneous reactance, and I should like to know whether this has been done in practice. It seems to me that the condenser method is the most ideal for purposes of regulation, because condensers will deal with power-factor variation and pressure variation, and the transmission losses will be kept low : the kVA load on the alternators is also reduced. If static condensers could be built for 6 600 volts, and I see no reason why they should not be, the loss in them would be much smaller than with moving synchronous condensers and they would require less attention. One point that is not touched upon in the paper is the question of the earthing of the neutral point where power has to be transmitted between two interconnected stations in both directions.

Professor E. W. Marchant : I should like to say a word on the purely economical side of interconnection, because it is very important. It is necessary first of all to consider the question of interconnection purely from the point of view of economy. I have worked out from figures given in the paper—I understand they are on the high side—the actual cost of transmitting energy over the 6 600-volt cable, data for which are given in Table 2 ; the figures work out

at almost exactly 0·01d. per kilowatt-hour per mile, for transmission. If two power stations are separated by any distance it is easy to find out from that figure whether it is going to be really economical to interconnect the stations, that is, to put additional plant in one station or to increase the plant in both of them. If it will be cheaper to take coal to one station rather than to the other, by the amount corresponding to 0·01d., then the interconnection is sound from the purely economical standpoint. That is only one side of interconnection. The other side of the question is what we might call the insurance side. If there is an interconnecting cable between two such stations as those given in the paper it will cost about £100 000 to install, but 10 000 kW of spare plant will be saved in one or other of the stations, because instead of putting spare plant in both stations it has to be put in only one, and it therefore seems to me from the insurance point of view that the cost of an interconnection cable can be balanced against the cost of spare plant. From that point of view it is cheaper to install cables than additional plant, which is certainly going to cost more than £100 000. I have not calculated the probabilities of breakdown occurring simultaneously in these stations, but obviously it will be very small. If the probability of a breakdown in one station is taken to be 1/100, then the probability of a breakdown occurring in the two simultaneously will be 1/10 000. The risk of breakdown in the cables is smaller still, and I think the assumption I have made, that the interconnection is equivalent to spare plant, is justified from the insurance side of the question. The cost of the cable can be set against that of the plant. It is clear from the paper that there is an economic limit to the distance over which interconnection can be successfully carried out. Now I come to the operating side, which is the main subject of discussion in the paper. The problem of running two stations in parallel seems to be fairly simple, but it is not actually so simple as it seems. To ensure successful parallel running between generators, a large synchronizing power is usually necessary, and the current flowing in the interconnector for this purpose must lag nearly 90 degrees behind the difference in the pressures at the generating stations. The transmission of power between the two stations will alter the phase of the synchronizing current, and I should like to ask the authors whether they have heard of any difficulties in parallel running with interconnected stations. It should be possible to compensate for the additional resistance and reactance inserted in the path between the two parallel-running generators, by the use of boosters. Where long cables only are used for interconnection, I should imagine that there might be considerable difficulty. The synchronizing power between the two stations must be less than when the two generators are side by side. To emphasize that point take a modern machine, in which the resistance of the stator absorbs from $\frac{1}{4}$ to $\frac{1}{2}$ per cent of the full potential difference when full-load current is passing. In the interconnector about 10 per cent of full-load pressure is absorbed when full-load current is passing, i.e. there is 20 times as much resistance as there would be if the two machines were side by side, and it follows that the synchronizing power must be very much reduced.

Mr. L. Breach : One of the authors suggested that I should say a few words in reference to the last slide which they showed. The slide refers to that part of the system of the Hydro-Electric Commission of Ontario which is supplied from plant at Niagara Falls. There were 4 stations when I was there, and a fifth has been put into operation quite recently. On the American side there is one station of 400 000 kVA capacity, and on the Canadian side two of 100 000 kVA each and one of 200 000 kVA. This latter is the only one at present under the control of the Commission, though the 800 000 kVA are coupled and feed into this system and other systems. These four stations generate about 12 000 000 kWh per day, while other steam-driven plant of about 200 000 kVA feeds into the systems, making a total of about 1 000 000 kVA interconnected. While I was visiting one of the steam stations the question of power factor was brought home to me very forcibly ; there were three 20 000-kVA and one 35 000-kVA sets installed, about 50 000 kVA being taken from the Falls 25 miles away by overhead transmission. The 35 000-kVA set was running with only 7 000 kW of load but about 22 000 kVA apparent load, and the power factor was 0·35. This 15 000-kVA wattless component was due to the Falls insisting on unity power factor ; and when one considers what it means in increased capital to the sending end in additional generating and transforming plant and also in transmission, one is not surprised at this insistence. At another Canadian station there were two 6 000-kVA rotary condensers at the end of two 75 000-volt transmission lines. These had their own transformers, automatic field and regulating gear, and high-pressure pumps to enable the condensers to start up as induction sets. This seemed to me to be very complicated and showed me most forcibly the necessity of always taking care of the power factor of the supply. It might be thought that the present paper deals with conditions which do not exist in this country, but this is not so, as in the case to which I have referred the supply and receiving ends were only 25 miles apart. I agree with the authors' statement that constant voltage should be kept at both sending and receiving ends, but surely if the transformers form part of a transmission line the busbar voltages could be kept constant by varying tappings on the winding of the transformers and allowing the power factor to swing with the load. It must be admitted, however, that Fig. 5 seems to point to the desirability of the induction regulator. I should like to know if the regulator in the sending end of one feeder and that in the receiving end of the same feeder can be adjusted electrically and coupled by pilot wires controlled by hand or automatically so that the adjustment is done from the sending end only, and whether this is advisable. I should also like to know the temperature-rise that might be expected in the regulator under normal conditions, and also the cost per kilovolt-ampere of the regulator.

Mr. H. Dickinson : I should like to know if the authors can say why the load factor is so much higher in the United States than in this country, as shown

in the table. Is it due to the system of selling at a contract rate of so much per lamp or so much per horse-power per annum, or to the fact that the factories work longer hours than is the custom in this country? At the bottom of page 289 a new type of boosting apparatus is referred to. I should be glad if the authors could give any information as to the principle upon which this apparatus is being developed.

Mr. A. E. Malpas: When we come to consider again the question of coupling up stations, the figures given in the paper might be of assistance. I was rather struck at the outset with the various difficulties that we are encountering; in fact, the first pages would lead a novice to expect that the problem had no solution, but towards the end of the paper I was rather comforted to know that in America they have carried out these long-distance interconnections and, as the authors point out, the problem there is slightly different from that in England, but it is a case that one meets with in different parts of the world. I have had it in my own experience in Spain, where we interconnected a 100-km line. In Madrid we had a gas power-driven station that was not very economical and reliable, and we had to go further afield and then install a 20 000-kW long-distance transmission. Coming to more recent times we have also a problem in this immediate neighbourhood where many outlying stations will have to link up. Bootle and Liverpool have already done so, but that is a short line and I should like to know what troubles were experienced.

Mr. C. Rettie: The serious breakdown which occurred in 1919 on the Chicago power supply system, which consists of three stations, divided into 4 sections and having a total capacity approaching 500 000 kW, was due to a short-circuit, and 18 minutes elapsed before synchronism was finally obtained. I should like the authors to say if, to their knowledge, the system of interconnectors referred to in the paper was in service in Chicago at the time of the breakdown, and, if not, whether the use of such a system would have saved the situation.

Mr. L. B. Wilson: There does not appear to be any mention in the paper as to how a receiving station would connect the transferred current to its supply. Taking the 10 000 kVA mentioned in the paper, would it be treated by the receiving station as a separate unit to replace a generator which for some reason has shut down, or as a general addition to the supply? If the former, then where the busbars were sectionalized and connected through reactances it would be necessary to have facilities for connecting up to any section of the busbar, or if the latter, where a permanent connection was made on to one section, it would probably necessitate the provision of busbar reactances of almost equivalent value to those already in use in other sections of the busbars. There would certainly be the inherent reactance of the inductor regulators and transformers, where used, but these, being the probable places where breakdowns would occur, could not be relied upon to limit the fault current, as under certain conditions the fault would be fed from at least two stations. If the authors think that additional reactances are necessary, how will the working of the inductor regulators be affected? In the case of stations which will be connected together, more or less permanently, it will not be possible to use the present method of earthing the neutral points of the generators at the different stations, owing to the heavy circulating currents which might arise, causing trouble to the telephone and telegraph services. If only one station were earthed, what would be the effect of this condition on the other? I think that a combination of reactances and a resistance has been used in one station for earthing the generators, and probably this method would be satisfactory for earthing interconnected stations; the neutral points of all the generators would be connected together through separate reactances to a common point at each station. These two points would be connected by means of an insulated cable which would be earthed through a single resistance. The circulating currents at triple frequency, between generators, would be taken care of by the reactances, which at this frequency have 3 times their nominal ohmic value, and any possibility of trouble due to resonance is prevented by the resistance in series with the reactances The amount of reactance mentioned as being inserted in the interconnector seems to be rather low. In many cases at the present time the insertion of 15 per cent, 20 per cent and 25 per cent reactance in these cables is being considered. How will the added reactance affect the regulators? When two stations are coupled together it is quite possible that with any fault between them they will be fed from two generators; where, therefore, is it proposed to put whatever protecting gear is required for the regulators, because when coupling up is proceeding the regulating gear will be one of the weakest points and will be fairly near the stations? In this case it would appear to be necessary to put in protecting gear such as reactances between the regulators and stations. If so, will they upset the operation of the stations?

Mr. H. Midgley: I should be glad if the authors in their reply would give a diagram of connections of an induction regulator, showing three phases. In the case of a consumer taking power at a low power factor, is it possible to save copper and reduce heating losses by installing an induction regulator and so loading the supply cable at unity power factor? If so, how would the regulator be connected up? I understand that where induction regulators have been installed in conjunction with interconnectors carrying varying loads, it is the usual practice for the operators to adjust them to suit the load at regular intervals, say every 10 minutes. I should like to know whether there would be any difficulties in the way of automatic operation. Professor Marchant touched on the synchronization of interconnected power stations, and I should like to amplify his remarks. If two stations are linked upon the high-tension side, and adjacent points which have a phase difference are found on their low-tension networks, what would be the effect of connecting these two points? Can the authors give any comparison of calculations and actual working figures obtained from such an interconnected system as the Newcastle Electric Supply Company? I should like them to incorporate in their reply the calculated figures for the loads on the

interconnectors of a system of three or more stations working in parallel.

Messrs. L. Romero and **J. B. Palmer** (*in reply*): Mr. Morton points out an error in the capacity of the booster given in col. 1 of Table 1. This has since been corrected for the *Journal*.

The determination of the most economical size of conductor to use for transmission lines did not form part of the scheme of the paper. For any given set of conditions it is of course a fairly simple problem, but in practice the principal condition, viz. the extent and duration of the load, is always unknown and has to be estimated. These estimates are often falsified by the event, and we think that for underground cables it is a safe rule when in doubt to select the larger size.

Mr. Morton's remarks on the effect of capacity current are interesting, and we agree that for long lines it would be of importance and would have to be fully considered.

The greater capacity of cables as compared with that of overhead lines will be quite an important advantage where long transmission lines are concerned, as the improvement of power factor on the whole system due to the capacity current of the cables will be very beneficial.

We have already dealt with the effect of capacity and the contra effect of the magnetizing current of transformers at greater length in our reply to the Manchester discussion (see page 811).

We would also refer Mr. Morton to our reply to the Manchester discussion on the question of the ratio of reactance to resistance.

We are not aware of any cases where the control of power factor in tie lines is obtained by varying the reactance in the line, although we see no reason why this method should not have a limited field of application in conjunction with fixed boost and transmission of power in one direction only.

When double-wound transformers are used in the tie line there is no difficulty about the earthing of the neutral points at both stations. If transformers are not employed the present Board of Trade rule allows the neutral point to be earthed at only one station, although in the light of American experience we are of opinion that this rule might very well be modified.

Professor Marchant's remarks on the economy and insurance sides of interconnection are most valuable, and he states that side of the question very clearly indeed. He also touches briefly on the chief technical points and we are in general agreement with what he says.

Mr. Breach gives some very interesting information about the system of the Hydro-Electric Commission of Ontario, emphasizing, as he says, the importance of taking care of the power factor of the system.

The method of controlling the power factor in the tie line by variable regulating tappings on the main transformers was mentioned in the paper, and is certainly the most economical if the practical difficulty of designing thoroughly reliable step-by-step switchgear for such high voltages and large currents can be overcome.

We have no doubt that the operation of two regulators, one at either end of the tie line, could be controlled together from one station only with the aid of pilot wires, but we do not think that the cost and complication of such an arrangement would ever be justified, as with boosters installed at both ends a pre-arranged system of control aided by the telephone should ensure satisfactory working.

Induction regulators are designed for the same maximum temperature as ordinary oil-insulated transformers, viz. 90° C.

In reply to Mr. Dickinson, the high load factors of the American power companies are due to numerous causes. The very large financial outlay involved in hydro-electric generation and long-distance transmission tends to limit the number of undertakings engaged in the industry; the area of supply of any one undertaking therefore is generally very large. This allows the greatest possible advantage to be taken of the diversity of industry and non-coincidence of peak loads. In California irrigation gives inherently a high load factor, and in addition the electrification of railways has been carried much further than in this country. There does not appear to be any tendency in the United States for the railway companies to erect power stations for their exclusive use, and the railway load is therefore an important factor in raising the load factor of the power companies' systems.

The boosting apparatus referred to on page 289 consists of a contactor-type step-by-step regulator in conjunction with static transformers, and is proving satisfactory.

We are sorry that we have not the necessary information about the Chicago power supply system to enable us to reply to Mr. Rettie's question.

Mr. Wilson asks how we would propose to connect the tie line to the busbars. Where busbar reactances are not employed the connection would be the same as for the other circuits, and even where busbar reactances are employed it would probably be quite safe to treat the tie line as a feeder circuit, owing to the fairly high inherent reactance of a line with step-up and step-down transformers at the ends.

We have already dealt with the subject of earthing the neutral point in replying to Mr. Morton and also in our reply to the London discussion (see page 301). We can only add here that the method of earthing the neutral points of two interconnected power stations by means of a special earthing cable between the two stations which Mr. Wilson mentions seems to us to be costly and unnecessary.

Mr. Midgley appears to have confused the functions of an induction regulator with those of a synchronous condenser. The induction regulator is simply a booster and does not improve the power factor of the system as a whole in the slightest, its only function in a tie line being to control the power factor of the load in the tie line or, in other words, to control the division of wattless current between the two stations without reducing the total wattless current to be supplied by the generators as a whole. The answer to his first question is, therefore, in the negative.

The automatic operation of induction regulators in the tie lines to keep the power factor constant would present no special difficulties. We would refer Mr.

Midgley to our reply to Mr. Howarth in the Manchester discussion in regard to the effect of interconnected networks in parallel with tie lines.

We can assure Mr. Midgley that our calculations agree with actual working results on interconnected systems. The method of calculation given in the paper can be applied as well to three or more interconnected stations as to two, and we therefore think that no useful purpose would be served by working out such examples here.

South Midland Centre, at Birmingham, 26 April, 1922.

Mr. R. A. Chattock: The paper deals with a very important subject from the power station engineer's point of view, and a question that is likely to assume greater importance in the future in view of the lines upon which supply is now being developed in this country. The authors deal more especially with the theoretical requirements for interconnecting a.c. power stations, and have apparently overlooked the practical requirements, which are quite as important. I wish to call attention to the practical difficulty of synchronizing and interconnecting two loaded stations after these have become disconnected due to any disturbance on the system. In the Birmingham Electric Supply Department there are two large-capacity stations and two stations of smaller capacity all running in parallel on one system, and, due to a disturbance on the system, two large sections of the supply were disconnected. In order to re-interconnect them, very great care had to be taken to get the two sides running in perfect synchronism before the connection was made, as otherwise a very heavy strain would probably have been thrown on to the system at the moment of closing the interconnector, due to the inertia of all the plant running on circuit—both generators and motors—which had to be pulled into synchronism if the two sides were not exactly in step. Such a strain, if it occurred, would probably set up a very heavy surge on the system, and would most likely have the effect of again opening the interconnector. It is generally found necessary to have men standing by to throw in additional interconnecting cables directly the first one is connected, so as to give ample capacity in the link for dealing with a surge of reasonable dimensions. What arrangements are made in the large American undertakings referred to in the paper, for metering the current that is interchanged? This current might be passing in one direction one day and in an opposite direction the next, and it would be interesting to know how the practical difficulties are obviated.

Mr. W. Lawson: The authors do not state whether the values given in Table 1 for transmission losses as a percentage of kilowatts delivered include booster and transformer losses. I should be glad to know the extent of these losses. Although the booster and transformer losses are probably small relatively, they should obviously be included in the losses involved in the scheme of interconnection. It is clear that the transmission losses in the interconnector can under certain circumstances be considerable, and it is desirable that in the parallel working of power stations they should be ascertainable. The consideration of these losses raises the question as to whether they should be put down to generation or distribution. In the simple case of two stations linked up by an interconnector which is not connected to the network at any point between the stations, the interconnector may be regarded purely as a busbar, and the two stations as portions of one larger station. In this case it would appear that in calculating the efficiency of the stations the losses in the interconnector should be taken into account. A method of ascertaining the transmission losses is to install at each station two watt-hour meters, one to measure the input and the other the output, each meter having a ratchet and pawl attachment to prevent reverse registration. With this arrangement the total kWh lost in the interconnector would be represented by the difference between the kWh registered by the output meters and those registered by the input meters. Changes in the direction of the load transmitted would not affect the accuracy of the result. It should be borne in mind, however, that this method would not entirely hold good if the interconnector were used to supply feeders along its route. In such a case the kWh delivered to the feeders would have to be metered and taken into account in computing the losses in the interconnector. The authors' statement as to the effects of power-factor variation shows the importance of ensuring that the power factor is accurately measured, as a false indication of the instrument might lead to the undesirable effects described being created unknowingly. I suggest that the use of graphic recording instruments at both ends of the interconnector would be advantageous as affording a convenient means to the engineer for ascertaining whether the prescribed conditions of operation are being maintained.

Mr. W. Wilson: The authors have not devoted a section to the advantages of interconnection, and I think that a few words from them would be of interest, if for no other reason than to bring home the importance of their subject. There is, however, one advantage which is made evident in the last appendix. This advantage is an indirect one, which might be overlooked until actual working had brought it to light. The undertakings in this country are largely of municipal origin, instituted by a borough or city authority to supply the needs of a limited area. The result has been that in addition to their being on the whole comparatively small and inefficient, the tendency has been not to see much further than the supply of street lamps, the lighting of the more accessible shops and dwellings, and such favourable motor loads as have come within the reticulation. Thus the cost of current, even where it is easily available, is on the average much too high, the load factors are far too low, and the use of electricity is enjoyed by but a favoured few town dwellers. A policy of interconnection, by joining up the separate plants into a combined system, would, in addition to its other advantages, bring the supply within the reach of many other less favourably situated customers, with consequent improvement in these various respects. It is by the

provision of power for the host of miscellaneous consumers situated away from the dense part of the town, such as brick works, flour mills, tanneries, dairy factories and farms, that the good load factors experienced abroad, and evident in the list given on page 297, are secured. It may be interesting to mention that the two islands of New Zealand, each of which has a length approximating to that of the power area in the Western States illustrated by one of the lantern slides shown, namely about 550 miles, are being equipped with generating plant in a series of large hydro-electric stations, which are designed to be interconnected much in the manner described in the last appendix. The schemes are being laid out with that end in view, and already the advantages of a high load factor have been experienced. There is no doubt, on the other hand, that harm has been done in the past by considering interconnection as a substitute for centralization, in the case of districts like Greater London which are supplied by a large collection of miscellaneous, small stations. The improvement of the London supply by the institution of a few large plants, in place of the extraordinary number of small ones that did the work in the past, appears to have been considerably delayed by the recurring proposal to interlink the existing stations, an expedient which, according to the supporters of the proposal, would effect the same end. As a matter of fact, until the war the two schemes mutually conflicted and neither was carried out; but there is little doubt that the result of joining together these heterogeneous plants would have been chiefly to increase the overhead charges without securing anything like a corresponding advantage. In the main, however, interconnection is a most important principle.

Mr. G. Rogers: The interconnection of generating stations belonging to the same authority and situated at no great distance apart offers no special difficulty. In such cases it is largely a matter of careful design of the interconnector and feeder system, with particular attention to the sectionalizing of the busbars into groups with graded reactances to minimize trouble under fault conditions. The transfer of load to meet changing conditions can be readily effected by voltage variation and adjustment of the steam supply to the generators, without the necessity for booster plant. In Birmingham the interconnection of the generating stations is effected by a combination of tie lines and feeders which feed into substations situated between the generating stations. The arrangement is very satisfactory and efficient. The problem as it affects power stations belonging to different authorities and situated at considerable distances apart becomes a different proposition.

The authors have shown very clearly the difficulties involved. A study of Table 1 emphasizes the fact that the power factor of the transferred load is one of the vital points to be determined. In the hypothetical case taken it would appear that to transmit the load at unity power factor—the most economical condition as far as the interconnector feeder is concerned—would make the position of the receiving station rather unfortunate in so far as it has to deal with a very large wattless component. It is obvious that in such a case amicable co-operation by the authorities concerned would be necessary to arrive at a definite design of interconnection, power factor of the load to be transmitted, choice of booster plant, and the best means of dealing with the wattless component. If possible, the combination of tie lines and interconnector feeders feeding into common substations would be advantageous in most cases. In regard to the types of booster plant, I consider that the induction regulator, though expensive, is the best to adopt. It is a most reliable apparatus and does not seem to offer the difficulties involved in a step-by-step regulator.

Messrs. L. Romero and **J. B. Palmer** (*in reply*): We are inclined to think that the difficulties experienced by Mr. Chattock in synchronizing and interconnecting two large loaded stations must be due to some special conditions obtaining on his system, as we have not encountered in our experience difficulties of this nature which were not overcome after a little practice in synchronizing. If the synchronizing is done at one of the power stations the usual plan is to close the switch when the station which is required to draw load is running at a very slightly lower speed than the other, after which the load is at once regulated by the governor control switches. We have had no experience of attempting to parallel two systems at a substation where the control of the steam supply could be carried out only over the telephone, but we can imagine that this might be a lengthy process and perhaps hardly feasible.

The metering problem which Mr. Chattock mentions is probably best dealt with in the manner explained by Mr. Lawson, with one meter to register input and the other output, but a.c. meters are made to register in both directions with sufficient accuracy, and if only the difference between input and output is required a standard meter could be used.

In reply to Mr. Lawson, the values given in Table 1 of the paper do not include the transformer iron losses and booster losses, as these losses do not affect the voltage condition. They do, however, include the transformer copper losses.

The transformer losses will prove the major portion of the total losses in a short interconnector employing step-up and step-down transformers, and in all interconnections employing transformers likely to be carried out in this country the transformer losses will be an important part of the total losses. The booster losses will generally be only a very small percentage of the total losses. We agree with Mr. Lawson that the losses in the interconnector should be taken into account in calculating the efficiencies of the stations, and we think that his suggestion for the use of graphic recording instruments is a good one.

Various speakers who have taken part in the discussion on our paper at other Centres have brought out the advantages of interconnection, and we will only add here that these advantages should be very considerable in an interconnected system designed and controlled under one supreme authority to obtain the maximum efficiency and reliability over the whole system, as the most economical plant available would be run at all times, and at week-ends and possibly at night only one station need be run. In addition, there would be a large saving on capital expenditure for spare plant.

We quite agree that the interconnection of a number of small, inefficient stations is not the best cure for their high costs.

The arrangement of interconnection mentioned by Mr. Rogers with tie lines and interconnecting feeders feeding common substations is a good one, but the power-factor effects on parallel feeders having different reactances and resistances should receive careful considerations before they are installed, particularly where transformers are employed in one line and not in the other, as undesirable and unexpected results might otherwise ensue.

DISCUSSION ON

"THE EFFECT OF HEAT ON THE ELECTRIC STRENGTH OF SOME COMMERCIAL INSULATING MATERIALS."*

Mr. A. Collins (*communicated*): The term "micarta" appears to have been used by the author to describe all materials composed of layers of paper stuck together with a varnish. This term however, is, generally understood to be a trade name describing only one variety of the product, and as a generic term "varnish-paper boards and tubes" is gradually being adopted. In the study of data dealing with such material as a class it must be remembered that, apart from being manufactured by various firms, individual firms may supply different grades depending upon the class of service. High dielectric properties may on occasion be of less importance than other features, and in any case the dielectric strength is not the only property to be considered when comparing the merits of different materials. Again, boards and moulded troughs may be made up of quite different materials from those used for transformer cylinders, bushings and terminals. This distinction is of importance when the results of tests are being compared. The section of the paper dealing with this material is of exceptional interest because of the rapid developments which are taking place in high-voltage oil-immersed apparatus for which, in the case of transformers, oil temperatures as high as 90° C. are permitted by the British Engineering Standards Association.

A study of Figs. 6, 7 and 8, particularly Figs. 6 and 8, gives rise to speculation as to the factor of safety of apparatus insulated with such materials, when the temperature of the oil approaches 90° C., and users of such apparatus may feel some cause for alarm when the author suggests that more satisfactory results are still to some extent in the experimental stage. Large quantities of "varnish-paper tubing" are employed in the construction of oil-immersed switchgear and transformers as bushes, terminals and cylinders, and this question of the effect of temperature has for a long time been fully appreciated by a number of engineers. Obviously, apparatus should be pressure-tested at the maximum permissible temperature, otherwise with characteristics similar to those illustrated in the paper the factor of safety may easily fall below unity at the higher temperatures. The testing of finished apparatus hot, or even the application of an equivalent test, may be inconvenient, but it is nearly always possible to test individual insulators or pieces of insulating material at the maximum permissible temperature of the apparatus. This has for some time been the practice of at least one firm in this country specializing in high-tension insulating materials. The paper will no doubt tend to make this condition more general. Some information as to the behaviour of the actual materials used in the manufacture of switch-

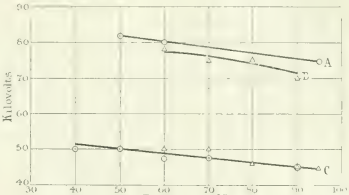


FIG. A.—Varnish-paper tube of British manufacture, tested in oil, voltage rapidly applied.

	Internal diam.	External diam.	Wall.
A.	$2\frac{1}{2}$ in.	$2\frac{7}{8}$ in.	$\frac{1}{16}$ in.
B.	$2\frac{1}{2}$ in.	$2\frac{5}{8}$ in.	$\frac{1}{16}$ in.
*C.	$2\frac{1}{2}$ in.	$2\frac{3}{4}$ in.	$\frac{1}{8}$ in.

* Two samples.

gear and transformer bushings and terminals should be of interest as a record of up-to-date practice, and as an illustration of the improvements that have resulted from systematic research.

Fig. A shows temperature/breakdown-voltage curves taken on four samples of tube. These samples were tested in the normal condition, without any special heat treatment, and the figures represent instantaneous breakdown, i.e. breakdowns obtained by raising the voltage rapidly, so that failure occurs in about 5 seconds. It has in the past so often been the practice among engineers to discuss insulation in terms of instantaneous breakdown that the curves have been produced in

* Paper by Mr. W. S. Flight (see page 218).

this form, although such data is not entirely satisfactory from the designer's point of view, and the results are to some extent a function of the testing apparatus. The only really useful data, as the author rightly points out, is the 1-minute figure, which takes into account the effect of the prolonged application of a high dielectric stress.

As an indication of the results obtained on relatively large thicknesses of material with prolonged application of dielectric stress, the following are some "time/breakdown" tests taken on tubes $2\frac{3}{8}$ inches (inside diameter) by $3\frac{3}{8}$ inches (outside diameter), in oil at 100° C. These tubes are typical of the material from which high-tension bushings are manufactured daily.

Sample A failed after application of 90 kV for 70 seconds.
Sample A failed after application of 96 kV for 15 seconds.
Sample B did not fail after application of 120 kV for 30 seconds.
Sample B did not fail after application of 100 kV for 240 seconds.

Both these results and Fig. A have been obtained on ordinary commercial materials of British manufacture, and are representative of material that is being supplied in large quantities for use in high-voltage oil-immersed apparatus. Appreciably better results have been obtained under specially controlled conditions of manufacture, and the possible benefits of further study and research are fully appreciated. No doubt improvements will continue to be made, but it is hoped that the foregoing figures will form a useful supplement to the data presented by the author.

Mr. W. S. Flight (*communicated reply*): The terms "micarta" and "micanite" were originally the trade names given to certain insulating materials by the firms who first placed these particular products on the market. In this country each of these terms has been used in a generic sense, and in the paper the term "micarta" was so used to indicate all materials composed of layers of paper stuck together with varnish. In a similar way the term "micanite" is used to indicate any material composed of layers of mica stuck together with varnish. The use of the term "micarta" does not, however, appear to have been so general as the use of the term "micanite," and recently the Electrical Research Association has decided that the recognized generic term for these latter materials should be "varnish-paper boards, tubes, etc." Although this later term is not as handy as the older one it has advantages, inasmuch as it describes the material in question, and at the same time prevents it from being confused with micanite. Mr. Collins calls attention to the fact that individual firms produce different grades of varnish-paper boards and tubes, depending on the class of service for which the material is required. This fact was recognized at the time the investigation was made, and, in order to obtain average representative values, tests were carried out on as many different grades of these materials as could then be obtained. From Table 7 it will be seen that these include a number of different papers and also a number of different bonds. As the main object of the investigation was to obtain data on the materials available for the insulation of high-voltage core-type transformers, practically all the samples tested were in the form of cylinders about 8 inches diameter, or of flat sheets. No attempt was made to compare results obtained on these shapes with those obtained on smaller tubes or moulded troughs, etc. As the manufacture of the above-mentioned shapes requires different machinery and sometimes a different process, it is only to be expected that the characteristics of the micarta will, to a certain extent, be influenced by the shape. As long as the same materials are employed in each case, and as long as the process of manufacture is similar, the variation in the characteristics obtained should not, however, be large.

Mr. Collins refers to the slope of the curves at the high temperatures in Figs. 6, 7 and 8, from which it is evident that materials of this nature are unsuitable for use at high temperatures. The above curves were typical of many of the micartas offered to manufacturers at the time these tests were made, viz. about two years ago, and unfortunately are still typical of many of the grades of varnish-paper boards and tubes which are still on the market. Largely as a result of this investigation, attention was given, by the company with which the author was connected, to the manufacture of varnish-paper boards and tubes having a higher electric strength when hot than those materials previously available. An interesting example of one of these improved grades of varnish-paper tubes is given in Fig. 10. The curves supplied by Mr. Collins and shown in Fig. A are extremely interesting, and show that other firms also have given attention to this problem and have developed varnish-paper tubes having satisfactory electric strengths at high temperatures.

It should be noted that the curves in Fig. A have been obtained by applying the voltage rapidly, whereas the author's curves were all obtained after the application of a high voltage for at least 1 minute. Not only does the latter method of test give a more practical value, but the results obtained give a better indication of the real behaviour of the material than does the rapidly applied test. As pointed out in the paper, the rapid decrease in the electric strength of inferior grades of varnish-paper boards and tubes at high temperatures can be attributed to the formation of various distillates which are given off by the bond employed. This distillation is caused partly by the initial temperature of the material and partly by the heat generated by the leakage currents which flow through the material when subjected to voltage stress. The rise in temperature due to the I^2R loss, the formation of distillates, and the lining-up of the conducting particles is a process which requires a certain amount of time. When inferior materials are tested at high temperature on the 1-minute basis they have been found to be conductors when at 100° C., as shown in Table 7. Had the same materials been tested by the rapidly applied method they might not have shown this characteristic, and might possibly have indicated a reasonable electric strength.

The interesting figures which Mr. Collins gives for the high-tension bushings (samples A and B) prove that they have been made from a superior grade of

varnish-paper tube, and one which does not suffer the rapid decrease in electric strength at high temperatures, which is such a marked characteristic of the inferior grades of these materials. Now that these improved grades of varnish-paper articles are available, both the purchaser and the user should insist on the electric strength test being carried out by the application of a reasonable voltage for at least 1 minute when the material is at a temperature of 90–100° C.

Since the publication of the paper it has been suggested to the author that varnish-paper boards and tubes are unsuitable for use at high temperatures. As the result of the tests recorded, and of many others, the author entirely disagrees with this statement. The lessons to be learnt from the curves given on page 226 are that varnish-paper boards and tubes intended for use at high temperatures should be purchased on the electric strength obtained only when the material is tested at a high temperature, say at 100° C., and when the voltage is slowly applied as indicated on page 219, or by some other approved time/voltage method. The practice of purchasing a material on the electric strength obtained by rapid application of the voltage at air temperature is strongly to be condemned, for not only is it entirely unscientific but the results are so misleading that it has often led to the failure of electrical machinery and apparatus. As the latter have always to withstand the voltage test for at least 1 minute at their maximum operating temperature, it is absurd to judge the insulating materials used on the characteristics obtained under any other conditions than those which will have to be met in the finished apparatus.

DISCUSSION ON

"INDUCTION-TYPE SYNCHRONOUS MOTORS."*

WESTERN CENTRE, AT BRISTOL, 6 MARCH, 1922.

Major E. I. David : The astonishing fact brought out by the discussions on this paper is that although these motors have been manufactured in this country for 10 or 12 years, and abroad for 20 years, no operating experiences were given by any of the speakers. Installations which have been running for 5 or 6 weeks were referred to, and experiments made in converting existing induction motors into synchronous induction motors were mentioned, but of actual day-to-day experience over long periods there is nothing. In view of the fact that the system with which I am connected has had a number of synchronous induction motors running for some time, of a total horse-power of 2 655, possibly the experience of the past 12 months in connection with these machines may be of interest. The motors are used for driving fans and compressors, for which the author says they are particularly suited. One motor of 1 125 h.p. and one of 450 h.p. drive compressors, and individual motors of 250, 280, and 550 h.p. respectively, drive fans through reduction gearing. In addition to the above machines, two 1 125-h.p. salient-pole synchronous motors are used for driving compressors, and further, an 1 125-h.p. motor with a phase advancer, and a similar machine without a phase advancer, are also used for the same purpose. A comparison between the running of these 5 machines of varying types is therefore possible. The author invites a comparison between the synchronous induction motor and the plain synchronous motor, and gives the impression that the process of starting a synchronous induction motor is considerably simpler than that of starting a salient-pole motor, whereas in fact the actions are almost identical. I give below in tabular form the process :—

No. of operation	Synchronous induction motor	Salient-pole synchronous motor	Induction motor with phase advancer
1	Close main switch	Same as S.I.M.	Same as S.I.M.
2	Cut-out resistance in starter and short-circuit	Close compensator switch	Same as S.I.M.
3	Bring up excitation volts to starting condition	Same as S.I.M.	No corresponding operation
4	Open rotor circuit	Close field switch	Throw over from starter to slip-regulator
5	Close field switch	Close full-voltage switch	—

When it is remembered that for induction motors the starter has to be carefully returned to the full-out position ready for the next start, the actual number of operations is greater than in the case of salient-pole

* Paper by Mr. L. H. A. Carr (see pages 165, 342, and 545).

machines. Fig. G illustrates an attempt to start a 280-h.p. synchronous induction motor direct coupled to a Walker fan. The attempt failed owing to the fact that the residual resistance in the starter was so high that when the starter was short-circuited a heavy surge took place owing to the motor endeavouring to accelerate from the heavy slip speed to small slip speed. Fig. H illustrates a second attempt to start this machine, but in this instance the clutch connecting the motor to the fan was withdrawn, and the motor was therefore starting up light. It will be seen that there is no difficulty in running up to speed, short-circuiting the starter and changing over from starter to exciter connections when the motor is running light, but even in this

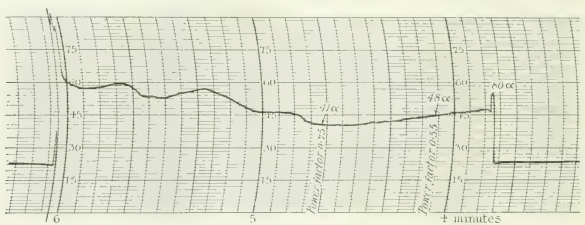


FIG. G.

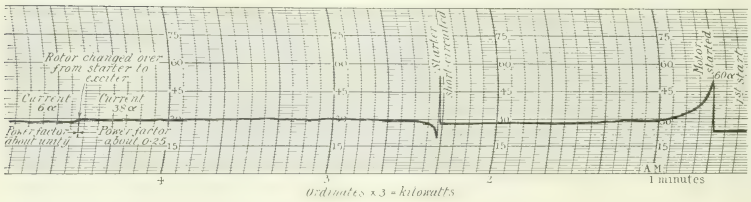


FIG. H.

that could be obtained from the various meters is given on this chart. It will be seen that this machine can be started, run up to speed and synchronized in less than 1 minute, the peak load being less than one-half full-load kilowatts. This machine was started through a starting compensator of the auto-transformer type, the starting tap being 40 per cent of full pressure. In this start the full-voltage tap was closed before the field switch. This gives quicker synchronizing, but is inclined to strain the insulation of the field windings. Fig. L illustrates a further start with this motor, in which the field switch was closed with the motor supplied through the 40 per cent tap, and a number of oscillations took place before the motor

instance a decided surge is shown when the starter is short-circuited. It will be noted that the starter resistance is still not high enough to prevent a fairly high current at starting, the peak being approximately 136 per cent of full-load current. It will be seen, therefore, that the resistance of the starter could not be reduced. The performance curves of this particular motor are given in Fig. 14 of the paper. As a comparison I give in Fig. J the starting curve of an ordinary induction motor driving a similar fan, from which it will be seen that it is quite a simple matter to start up a fan with this type of motor and that there is no excessive surge on short-circuiting the starter. Fig. K shows the starting, synchronizing and loading of an 1 125-h.p. salient-pole synchronous motor direct coupled to a two-cylinder air compressor. Every possible detail actually synchronized. From the above it is evident that the salient-pole synchronous motor is equally as good as the synchronous induction motor for starting compressors, and the ordinary induction motor is preferable to the synchronous induction motor for starting fans. The efficiency of the salient-pole synchronous motor is normally at least 2 per cent higher than that of the synchronous induction motor. In the case of the 1 125-h.p. motor referred to above, the efficiency of the salient-pole motor was 95·8 per cent on test at unity power factor, and of the synchronous induction motor 93·75 per cent at unity power factor. The corresponding efficiencies at 0·9 leading power factor are 94·9 and 93 per cent respectively. A difference in efficiency of 2 per cent on a continuous running machine such as a colliery compressor of this size represents something

like £300 per annum. On smaller machines particularly at 0·8 leading power factor the difference is up to 4 or 5 per cent. The reason for this lower efficiency in the synchronous induction motor is accounted for partly by the greater excitation, the figures being 17 kW at full load. The plain induction motor with phase advancer can be made up to 0·9 leading power factor, which is about the economical limit of the synchronous induction motor.

(*b*) The leading power factor of the synchronous

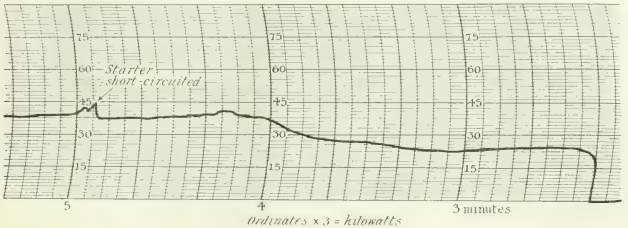


FIG. J.

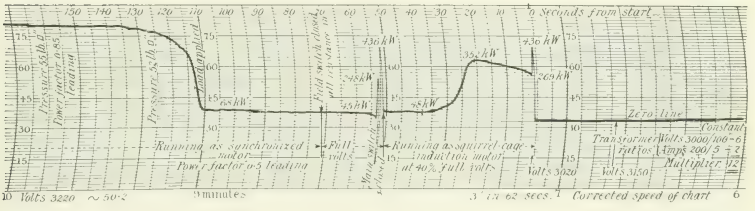


FIG. K.

Main switch closed
Field switch closed with phase advancer or main field rheostat resistance all in
Compensator closed on 40% tap

FIG. L.

for an 1 125-h.p. salient-pole motor, and 23 kW for the synchronous induction motor, at 0·9 leading power factor in each case. The conclusions arrived at from the above and other experiences are as follows:—

General advantages.—(*a*) The salient-pole machine can be designed for any leading power factor up to 0·7 induction motor increases at low loads, as does that of the salient-pole motor. This, however, is no great advantage as it is at heavy loads that the leading power factors are required to prevent excessive line drop.

(*c*) The action of a phase advancer in increasing the slip is an advantage in compressor machines as it permits

a higher cyclic irregularity and therefore a lighter flywheel. In mine fan drives it is also an advantage as it prevents shocks being transmitted to the system, due to sudden changes in the equivalent orifice, and therefore the load on the fan where the upcast shaft is used for winding. The slip can be made anything from 1 up to 15 per cent as desired, the phase advancer if required being designed to inject a voltage in opposition to the rotor voltage, as well as to supply the magnetizing current.

(*d*) The author compares commutators for low-pressure direct current for synchronous induction motors with low-pressure, low-frequency alternating current for salient-pole machines. I have had as much trouble in 12 months with the d.c. exciters as in 6 years with the a.c. slip-regulator. The slightest defect in the brushes or commutator reduces the output of the d.c. exciter, owing to the low voltage and heavy currents.

Overloads.—The salient-pole machine designed for a leading power factor of 0·85 has a pull-out torque of over 200 per cent; overloads greater than this should be dealt with by the circuit breaker, not by the motor. The claim of the synchronous induction motor of advantage due to the higher pull-out torque as an induction motor is not borne out in practice. The change from synchronous to induction running is accomplished by violent surging. To change a heavy load from 0·9 leading power factor to 0·7 lagging power factor with the accompaniment of violent surging would not be considered an advantage by any power engineer. Further, the salient-pole machine will hold in synchronism at full load with a drop of supply volts up to 50 per cent, whereas 25 per cent would be about the limit of the synchronous induction motor.

Suitability. Starting.—For compressors the synchronous induction motor has no advantage over a salient-pole motor. For fans it is decidedly inferior to a plain induction motor, owing to its high starting voltage and resulting difficulties in short-circuiting under heavy load.

General suitability.—The salient-pole motor, owing to its large air-gap and rugged rotor construction, is particularly suited for direct coupling to high-speed compressors of the piston type. No intermediate bearing is required, resulting in a saving in length of nearly 3 ft. The air-gap of an 1 125-h.p., 214-r.p.m. salient-pole motor is 280 mils, whereas that of a similar synchronous induction motor is 65 mils. The salient-pole motor exciter is a normal 110/160-volt machine against an abnormal 40/50-volt machine. The efficiency is 2 per cent higher. The slip-rings carry 150/160 amperes, as against 350/450 amperes. The starting gear is very similar. The liquid starter is replaced by an auto-transformer. The same number of switches and other instruments are required. The starting torque is ample for the purpose, and the starting current and kilowatts are only slightly greater.

Fans.—Reliability is essential for mine fan motors. A plain induction motor, with a simple rotor winding not subject to high-voltage shocks at starting, is inherently more reliable than the freak rotor of a synchronous induction motor. If power-factor improvement is required, a phase advancer, which may be used or not at will, meets all requirements, and may be added at any time as the mine load develops. If a clutch or other starting device is provided, then a salient-pole machine is preferable to a synchronous induction motor, for the reasons stated above.

Pumps.—Large mining pump motors running at 1 500 or 3 000 r.p.m. have usually high power factors of from 93 to 96 per cent. To obtain a leading power factor of 0·9 would entail a sacrifice in efficiency of 2 to 3 per cent, and require a high rotor starting voltage, increased complication, cost and liability to breakdown. Further, for colliery use the exciters would have to be totally enclosed, and all the switchgear flameproof. The reduced reliability would be sufficient to put it out of court in the opinion of a mining engineer.

For driving Ilgner sets, rolling mill drives or any drive where energy is required from the moving masses during peak loads, the plain induction motor with phase advancer slip-regulator, which can be arranged to give up to 15 per cent speed drop from light to full load, is preferable. A set of this type is installed in this district and drives a rolling mill. The plain induction motor without the slip-regulator has a power factor 5 to 10 per cent higher than that of the synchronous induction motor running as an induction motor. Below are given figures for a number of synchronous induction motors running as induction motors and one induction motor for comparison.

Power-factor improvement is a matter of the greatest importance to concerns with overhead transmission lines, in view of the heavy voltage-drop produced by low-power-factor currents in these lines. The previous discussions have shown that supply undertakings are

Type	Horse-power	Speed, r.p.m.	Power factors at different loads				
			¾	½	¼	⅛	Light
*S.I.M.	550	500	—	—	0·65	—	—	—
S.I.M.	1 125	214	0·72	0·7	0·68	—	0·45	—
†I.M.	1 125	214	0·84	0·83	—	—	—	—
S.I.M.	450	250	0·61	0·5	0·5	0·3	0·25	—
S.I.M.	250	750	0·86	0·80	0·75	—	—	—
S.I.M.	280	500	—	—	0·6	0·35	0·26	0·22

* Synchronous induction motor.

† Plain induction motor.

anxious to prove the advantage to consumers of improved power factors, but where the consumer and producer are one and the same the advantage is very evident. In addition to the machines already indicated for power-factor improvement, I have a 236-kVA static condenser in operation at 3 000 volts, and this has given very satisfactory results. In conclusion, I agree with the author that the synchronous induction motor can be made a satisfactory and reliable machine, but it is not the superlative machine that he endeavours to prove.

simple. On closing the stator high-tension oil switch the motor immediately started, and by the time the short-circuiting contacts of the liquid starter were reached the machine pulled into synchronism with no fluctuation on the line other than a momentary oscillation of the ammeter needle just when pulling in. The author only lightly touches on the advantages of raising a low power factor, and I think he might with advantage have gone into this matter in more detail. The desirability of using synchronous induction motors where suitable conditions prevail should be evident if one

Type	Comparative Price	Excitation	Power factor			Excitation at 0·8 power factor	Load			Air-gap
			1/1	¾	½		1/1	¾	½	
			Motor : 410 *h.p.*, 750 *r.p.m.*							
*S.P.M.	100	2·88	94	93	91	4·4	93	92	89·5	0·25
†S.I.M.	103	7·00	92	91	88·5	11·2	88·5	90·5	87	0·1
			Motor : 550 *h.p.*, 750 *r.p.m.*							
S.P.M.	100	3·78	95	94	92	5·72	94	93	90·5	0·25
S.I.M.	104·3	7·55	92·5	92	90	12·2	91	91	88·5	0·09
			Motor : 150 *h.p.*, 750 *r.p.m.*							
S.P.M.	100	1·8	93·5	92·5	89·5	2·75	92·5	91·5	88	0·22
S.I.M.	104·6	3·8	91·5	90·5	88·5	6·25	89	88·5	86·5	0·055

* S.P.M. = Salient-pole motor. † S.I.M. = Synchronous induction motor.

Mr. C. S. Buyers : I should like to refer first of all to the lantern slides illustrating synchronous induction motors manufactured by Messrs. Crompton & Co. The motors shown are all installed in the area covered by the Western Centre and are principally used for driving fans and compressors at collieries. I differ in opinion from one or two speakers in that I consider this type of motor to be, for several reasons, very suitable for driving the main fan at a colliery where the power factor may be as low as 0·6 lagging, a figure which is not uncommon at collieries. These are, first, that fan motors run at a fairly low speed and are in many instances underloaded for the first few years to allow for change of pulleys in the future when a greater volume of air is necessary. If a plain induction motor is used the power factor will naturally not be high in these circumstances, but a synchronous induction motor can be run at a leading power factor at any load, thus rectifying the effect of lagging currents in the system. Secondly, a fan motor runs for 6 days a week at a constant load and does not require to be started and stopped frequently, all of which are points in favour of the synchronous induction motor. Thirdly, the air-gap of a synchronous induction motor is generally greater than that of a plain induction motor, a matter considered of importance by colliery engineers, who rightly regard reliability as an essential feature of a fan motor. Some months ago I tested on site a 250-b.h.p. Crompton synchronous induction motor driving a colliery fan, and no difficulty was experienced when pulling into synchronism against full load. The whole operation of starting was very simple. On closing the stator high-tension oil switch the motor immediately started, and by the time the short-circuiting contacts of the liquid starter were reached the machine pulled into synchronism with no fluctuation on the line other than a momentary oscillation of the ammeter needle just when pulling in. The author only lightly touches on the advantages of raising a low power factor, and I think he might with advantage have gone into this matter in more detail. The desirability of using synchronous induction motors where suitable conditions prevail should be evident if one considers that the losses in a system operating at 0·7 power factor are twice as great as when operating at unity power factor, or that, in other words, for equal efficiency twice the sectional area of copper is necessary. There are also the disadvantages that alternators, transformers, etc., work at a higher temperature, the voltage regulation is adversely affected, and exciters may be overloaded. The author does not include in his figures showing the various methods of connecting the rotor windings of synchronous induction motors the scheme adopted by Messrs. Crompton & Co. Their method is to wind the rotor two-phase and to connect the neutral point of the rotor winding directly in series with the exciter armature and with the dippers of a two-phase liquid starter, the two free ends of the rotor winding being connected to the insulated pots of the starter. As the dippers of the liquid starter are connected to earth, the exciter is always at earth potential at starting, even if the slip-ring voltage be as high as 2 000 volts. With this arrangement the starting apparatus is exactly as for an induction motor and can be operated by unskilled labour. A previous speaker has mentioned the case of driving high-speed centrifugal pumps. I should like to ask the author if he considers the synchronous induction motor to be suitable for driving a pump when a motor of, say, 300 h.p. at 1 500 r.p.m. is required. Owing to the excellent power factor obtainable from high-speed induction motors it appears to me that the extra cost of supplying an exciter is not justified in such cases.

Mr. D. Weir : The synchronous induction motor

is technically an interesting machine, but there are grave doubts among some of the leading manufacturers and among many operating engineers as to the suitability of this type of motor for the drives commonly met with in practice. For one instance in which the synchronous induction motor can be used advantageously there are 10 in which the ordinary salient-pole synchronous motor shows up to much greater advantage. The only advantage that the synchronous induction motor can claim over the self-synchronizing salient-pole machine is its high starting torque, but this advantage is obtained at a somewhat formidable price, not only in the matter of initial cost, but also in efficiency, robustness and, to a certain extent, stability. Where, owing to the nature of the load, it is impossible to avoid the necessity of a high starting torque in the motor, it may be considered advisable to pay this price. Even in such cases the alternative scheme of driving the load through a clutch should not be overlooked. There are several reliable and satisfactory clutches on the market, and the price of a salient-pole synchronous motor plus clutch will in most cases be less than that of a synchronous induction motor alone. How few cases are there in practice where a high starting torque is really unavoidable? The author has stated that the principal fields for the synchronous induction motor are air compressors, fans and pumps. It is a simple matter to unload air compressors during starting and, in fact, the majority of compressors are now fitted with an unloading device irrespective of the type of motor or prime mover driving them. Fans can also be unloaded by closing the inlet or outlet during the starting period. It may be mentioned in passing that this scheme has been applied with unqualified success to mine ventilating fans on the Rand. With pumps, the unloading is equally simple. All that is necessary is to fit the pump with a by-pass valve which is opened before starting up and closed when the motor is up to speed. In all these cases the starting torque required is reduced by the means indicated to about one-quarter or at most one-third of full-load torque, and under such conditions the ordinary salient-pole machine will easily start up the load with approximately full-load current from the line. The number of salient-pole machines which has for years been in operation all over the world driving compressors, fans, pumps and line shafting, is sufficient evidence of the success of this type of machine for such drives. Against the advantage of high starting torque of the synchronous induction motor we have to put the following disadvantages, (1) low efficiency; (2) high initial cost; (3) small air-gap (necessitating for a sound job two bearings and a solid cast-iron bedplate for the motor); (4) unsuitability (i.e. economically) of this type of machine for unity-power-factor operation; and (5) necessity of providing a special low-voltage exciter. These disadvantages represent the price which has to be paid for a high starting torque. It would surely be better to employ one of the comparatively simple devices referred to for unloading the apparatus during the starting period. The author admits that the efficiency of the synchronous induction motor is 1 per cent lower than that of the corresponding induction motor. It may, however, be 2 or even 3 per cent lower in some cases. The salient-pole machine for unity-power-factor operation on the other hand will on the average be 2 per cent better in efficiency than the corresponding induction motor, or (taking the author's figure of 1 per cent) the salient-pole machine is at least 3 per cent better than the corresponding synchronous induction motor. In some cases it may be even 4 to 5 per cent better. If the salient-pole machine be designed for 0·9 power factor leading, the efficiency will still be 2 to 4 per cent better than that of the synchronous induction motor. This is a very material advantage of the salient-pole machine. The author states that the price of the synchronous induction motor with starting gear and switchgear is anything from 25 to 40 per cent more than that of the corresponding induction motor. This is a very fair estimate. The unity-power-factor salient-pole machine, on the other hand, with starting gear and switchgear, and including a separate exciter, in many cases comes out no higher in price than the induction motor equipment. In other cases it may be anything up to 15 per cent higher. These figures refer, of course, to machines above 100 h.p. as is the case with the author's figures, and are based on numerous actual cases of recent data. We see then that on the average the synchronous induction motor equipment is approximately 23 per cent dearer than the salient-pole equipment, which is again a very marked advantage for the latter. This advantage is materially increased if, as is frequently possible with the salient-pole machine, the separate exciter is dispensed with. Such a possibility does not exist in the case of the synchronous induction motor. With regard to the small air-gap, it is futile to dismiss this objection by drawing attention to the thousands of induction motors in daily use. Those who have to maintain a large installation of induction motors know what a real difficulty the small air-gap is. The small air-gap is a necessary evil if the numerous advantages of the ordinary induction motor are to be realized; consequently we have to put up with the inconvenience resulting from this undesirable feature. One might as speciously argue that the pneumatic tyre has no real disadvantages since there are millions in use. True, the synchronous-induction motor has an air-gap 30 per cent greater than in the case of the corresponding induction motor, but nevertheless it is, even at that, still a small air-gap. Why retain this undesirable feature unnecessarily in those cases where a synchronous machine can be installed? The salient-pole machine has a gap 4 to 6 times as large as that of the synchronous induction motor. On account of its large air-gap a sound salient-pole machine can be built with one pedestal bearing in place of two, and small foundation caps in place of the massive bedplate that is necessary or at least highly desirable with a machine having a small air-gap. That the low-voltage exciter is a troublesome feature has been borne out by Major David's remarks. The salient-pole machine need not have a separate exciter at all if a d.c. supply is available at any voltage up to 220. Numerous cases occur where a user does not wish a machine for leading-power-factor operation. In such cases the same size of synchronous induction motor must be installed as for 0·9 leading

power factor in order to get a reasonable overload capacity. The salient-pole machine, on the other hand, can easily be built for unity-power-factor operation, and also to give twice full-load torque, and thus advantage can be taken of the unity-power-factor operation to use the most economical frame size. When one considers these very serious drawbacks, the attitude of a few important manufacturers in this country and the majority of the large American manufacturers in refusing to build the synchronous induction motor except in very special cases is quite understandable. The B.T.H. Co. built synchronous induction motors some years ago, but stopped their manufacture when the inherent shortcomings of this type of machine became apparent. It was then realized that if the synchronous induction motor had a useful field it was a very limited one indeed.

Mr. P. J. Plevin: I have always understood that the advantage possessed by the synchronous induction motor over the salient-pole synchronous motor lies in its high starting torque and low starting current as compared with the comparatively low starting torque and heavy starting current of the salient-pole type. The author mentioned that the human element may materially affect the value of the starting current of a synchronous induction motor, and that by ill-judged switching-in this might exceed the normal by no less than $2\frac{1}{2}$ times. Such a figure is well above the average of the starting currents of salient-pole synchronous machines as guaranteed by the makers and, as expert operation cannot always be depended upon, it would seem that one of the chief advantages claimed for the synchronous induction type over the salient-pole synchronous type vanishes, unless the latter is similarly affected. I should like to know what the maximum starting current of a salient-pole synchronous motor would be under similar conditions.

Mr. C. C. Atchison: The general trend of the paper and discussion appears to be that a better power factor is wanted on future plant or to rectify poor power factor of existing plant, in order to assist the supply engineer. Where the generating plant belongs to the private concern they could look after their own troubles, but in the supply undertaking it is a different matter. Supply engineers have not taken enough cognizance of power factor in the past and are now experiencing trouble. When I first commenced to supply three-phase alternating current I made inquiry as to methods of charging and found that English engineers had not taken power factor into account, but abroad I found some supply undertakings did so and charged a higher price for supplies at lower power factor. If supply undertakings had taken up the question of power factor in some such way originally, we should have had some suitable plant installed and Messrs. Crompton would not be receiving so many inquiries as to how to rectify the present troubles.

Professor D. Robertson: The author gives some figures concerning the action of the synchronous induction machine with the exciter in circuit. Can he say what the difference would be with the exciter out of circuit?

Mr. C. T. Allan: When power companies commenced operations they did not realize how power factor was going to affect them later. This commenced at about 0·8 and has gradually come down to 0·6 and even lower. One seldom sees an induction motor run fully loaded, and practically never overloaded. Consumers naturally buy the largest motors possible for their outlay. Tariffs nowadays are arranged to take care of power factor, thus inducing users to improve it. To do this, the arrangement described by the author has useful possibilities when applied to existing machines, probably saving extra expense in installing special phase advancers. I know of a case where a 1 300-kVA rotary condenser or phase advancer is being installed solely for the purpose of power-factor improvement.

Mr. L. H. A. Carr (*in reply*): In reply to Major David's remarks, I would point out that it is stated in the paper that the drives most favoured by operating engineers appear to be compressors, fans, and pumps. I quite agree that the modern salient-pole synchronous motor operates perfectly satisfactorily on compressor drives, and that there is no absolute need to introduce the synchronous induction motor for this duty, but the fact remains that many operating engineers prefer to install them for this duty on account of the larger margin in starting torque which they possess. Major David's comparison of the starting operations necessary with various types of motors is unfair to the synchronous induction motor. Operation No. 3 ("Bring up excitation volts to starting condition") does not in fact take place, since the exciter rheostat is left untouched in the running position, and operations 4 and 5 take place together by the operation of a single throw-over switch. The number of operations is therefore reduced to three, exactly the same as with the induction motor with phase advancer or plain induction motor with brush-lifting and short-circuiting device.

Major David's curves are most interesting and form a valuable addition to the available information on the subject. With regard to Figs. G and H, however, it is perfectly clear that the starter is for some reason not suitable for the duty. The attempt to jump at one step from a heavy slip speed to normal speed is always accompanied by a rush of current even on an induction motor, and if the residual resistance of the liquid starter immediately before short-circuit is too high, there will in any case be a heavy surge when the short-circuiting operation is carried out. The differences between the curves in Figs. G and J must therefore be blamed on the starter, and not on the type of motor employed, and one cannot agree with Major David's sweeping criticism that the ordinary induction motor is preferable to the synchronous induction motor for starting fans. Given equal conditions, the results are bound to be equally satisfactory. Major David quotes troubles on a d.c. exciter in connection with a synchronous induction motor. During the past 12 years I have had experience with something like 100 synchronous induction motors, and this is the first case of trouble with the exciter that has ever been brought to my knowledge. In fact, Major David's whole experience seems to have been unlucky with this type of machine, which appears to be brought out by the fact that despite the number of these machines

in operation, no serious criticisms have been raised by the engineers in charge of them, either in the discussion on this paper or elsewhere. For high-speed pumps where the normal induction motor has a high power factor, there is, I agree, little field for the synchronous induction motor, though 2-pole 25-period synchronous induction motors have been supplied for driving centrifugal pumps, while in at least one other case a high-speed pump has been driven by a synchronous induction motor in order to obtain power-factor correction for a group of small motors. For ram pumps, however, the synchronous induction motor holds the field where a large power-factor correction is essential.

Mr. Buyer's experiences with the synchronous induction motors are, I think, the more general experiences of engineers using this type of machine, that is to say perfectly satisfactory. The question of the two-phase rotor connection was raised by Mr. Johnson and Mr. Burge in the discussion at the Institution, and my objections to this method will be found in my reply to that discussion. The question of earthing does not really arise. With any method of connection the liquid starter is earthed, and with the 3-pole switching arrangement shown in the paper the exciter also can be earthed.

Mr. Weir is pessimistic as regards the efficiency of the synchronous induction motor, and I cannot agree with his conclusions as regards first cost, if the cost of the starting apparatus be taken into account. In this case, allowing for switchgear and an auto-transformer for the salient-pole machine, and for switchgear and a rotor starter for the synchronous induction machine, the prices of the two installations come out almost identical; sometimes the one is slightly cheaper, sometimes the other. Despite Mr. Weir's remarks, the number of firms in this country, as well as on the Continent, who are building synchronous induction motors is increasing rapidly, while signs are not wanting that American firms are looking into their possibilities.

Mr. Plevin seems to have rather misunderstood my remarks about starting current. The $2\frac{1}{2}$-times full-load current referred to was synchronizing current, not starting current, and from a typical oscillogram which I have, taken under working conditions, this figure is only reached during one period. The whole kick lasts only 5 periods, the current measuring about $1\frac{1}{4}$, $1\frac{3}{4}$, $2\frac{1}{4}$, $1\frac{3}{4}$, and $1\frac{1}{4}$ times full-load current at the peaks of 5 successive periods. This kick can scarcely be seen on an ordinary meter.

In reply to Prof. Robertson, with the exciter out of circuit the synchronous induction motor behaves exactly like an ordinary induction motor, and usually like such a motor with an overload capacity rather greater than normal.

DISCUSSION ON

"ROTARY CONVERTERS, WITH SPECIAL REFERENCE TO RAILWAY ELECTRIFICATION." *

North-Eastern Centre, at Newcastle, 13 February, 1922.

Mr. W. T. Dalton: In the introduction to the paper the author says: "If regenerative braking is found to be advantageous the equipments must be suitable for inverted operation." Does he refer to motor-generators or to rotary converters? If the latter, how is it intended to reverse automatically the series winding at the moment of reversal of the converter, either from alternating to direct current or vice versa, to make it suitable for regenerative operation? The methods employed by the author for getting rid of the conducting vapour to prevent successive flash-overs as the result of a short-circuit on the d.c. side, guards to protect the armature, and the protection provided for the brush-boxes, as shown in Figs. 5 and 6, would appear to be especially valuable where machines are installed in automatic substations. Under these conditions there will be no attendant to dress up commutators, etc., after the machine has been short-circuited due to line faults, and thus provision is made by the author to minimize the possibility of the machine being automatically switched on load again with damaged commutator and brushgear. The oscillograms shown in the paper are worth a great deal of study, as freedom from interference with telephones and telegraphs by electromagnetic or electrostatic disturbance will be of the greatest moment in the event of the railways being electrified. In this respect the central-battery telephone system appears to be the most sensitive to such interference, and it would help matters if the return conductor of railways were insulated from earth. Where the track rails form the return conductor the creosoted timber sleepers may prove of advantage as compared with tramways where the rails are in direct contact with earth throughout their length. Special negative insulated returns are in use on some railways, but this provision resolves itself into a question of economics in capital cost and distribution.

Mr. R. Townend: The author gives a voltage of 1 000 d.c. as the limiting figure for which a 50-period rotary converter can be conveniently designed. If we wish to increase this figure it is necessary to exceed one or more of the limits given for commutator peripheral speed, pitch of commutator bar and average voltage per commutator bar. By using a radial type of commutator a peripheral speed of 10 000 feet per minute should present no serious difficulties, and a small extension of the other two limits would then make a 1 500-volt, 50-period rotary converter a practical possibility. A machine of this type is at present being constructed, and test-results should be available in the near future. The d.c. brushgear fitted with a magnetic blow-out arrangement is most interesting, but unfortunately the paper gives little indication as to the construction of this feature. Fig. 10 shows a short-circuit on a machine fitted with this magnetic blow-out, but it appears that a propeller fan is also fitted to the commutator. It would be interesting to know how the machine would behave on a short-circuit with only the fan in operation, as I believe the air blast is by far the more effective method of limiting the flashing. It should be noted in comparing Figs. 8 and 10 that the former is a 40-period rotary converter and the latter a 25-period generator, and in general the prevention of flashing is much simpler in the case of a generator than in the case of a rotary converter. In connection with the prevention of flashing-over in the case of a generator, an interesting and effective arrangement is the "flash suppressor" devised by Mr. N. Storer of the Westinghouse Company. The arrangement consists of a very high-speed switch which, when tripped, short-circuits three slip-rings which are connected to suitable points of the armature winding. The short-circuit reduces the armature voltage to zero, and is so rapid in action that this occurs before any serious flash has had time to develop. The section of the paper on d.c. voltage ripples is most interesting and valuable, but I would suggest that the author adds to each figure a short description giving the conditions to which it refers.

Mr. C. Sykes: On a recent visit to the B.T.H. works at Rugby I saw a number of tests, including short-circuit tests, carried out on a 1 000-kW rotary converter. I understood that the machine had previously had some 37 short-circuits thrown on to it, and no buffing up of the commutator had been required. I was impressed by the absence of burning on the commutator and brushgear. From the appearance of the machine it could reasonably be assumed that it would continue to withstand the short-circuits indefinitely. The arc appeared to have been blown clear of the working surface of the commutator, and any burning visible was at the ends of the extended portion of the commutator segments. A number of photographs were taken which showed the arc to be clear of the commutator, and illustrated the effect of the special fan device. I am of opinion that the fan effect and the magnetic blow-out on the brush-arms undoubtedly served their purpose. The author has made no reference to the high-speed circuit breaker which was in operation whilst some of the tests were taking place, and which appeared to fulfil an important function in the breaking of heavy short-circuit currents. I should be glad if the author could give some details of this apparatus.

Mr. J. R. Beard: There is no doubt that of recent years the rotary converter has reached a higher pitch of perfection here than it has done in the United States, especially in its capacity for withstanding more severe

* Paper by Mr. F. P. Whitaker (see page 501).

short-circuits. I think this is probably due to the British user having always been in a stronger position relative to the manufacturer than is the case in America. Practically from the beginning of electric traction in this country the user has insisted on connecting his machines direct on to the track, while in America he has been persuaded to install long lengths of feeder cable to introduce sufficient resistance to cut down the short-circuit currents to manageable amounts. Our practice is more efficient, and by the user insisting on it the manufacturer has been forced to pay more attention to flash-over problems, with the results shown in the paper. The author refers to the satisfactory operation for the past 4 years of the machines illustrated in Figs. 7 and 8. I can confirm that flash-overs give no trouble at all and the machines can be relied on to clear the severest flash-over with the ordinary d.c. circuit breaker without tripping the machine on the a.c. side, and without appreciable blackening or burning of the commutator. Time after time they have been put straight back into service after a flash-over, by merely reclosing the d.c. circuit breaker. I am not clear as to whether the curves of efficiency in Fig. 12 include the losses in the transformers, which are, of course, greater at 25 periods. Also, the compounding curve shows normal voltage at twice normal load, whereas in the text the author states that it is preferable to compound for normal voltage at $1\frac{1}{2}$ times normal load. Recently I had occasion to examine the wear on the commutators of the rotary converters supplying the Tynemouth lines of the North-Eastern Railway. These machines have been running for 17 years and have continually had to deal with severe flash-overs and to have their commutators cleaned up. In spite of this, however, the radial wear is only $\frac{1}{4}$ inch, i.e. 68 years per inch of commutator. I am much indebted to the author for his very clear and logical analysis of the causes of telephone interference and the extent to which they can be avoided, but for completeness I suggest that he should add a second set of transference oscillations, viz. those which are transferred from the traction motors. I should like the author to say whether these are of appreciable magnitude and whether traction motor designers take steps to keep them to a minimum. In my own telephone experience I have frequently heard noises which seemed to correspond to the acceleration of such motors.

Mr. H. B. Poynder: Mr. Beard has mentioned the excellent behaviour of the rotary converters installed at Erimus substation, which are referred to and illustrated in the paper. I understand that the high-tension circuit breaker has opened only 3 or 4 times in the whole history of these machines, although of course they have been very frequently subjected to short-circuits, and in each of these cases there has been some definite reason for the high-tension circuit breaker opening. In one case, a mechanical defect of the d.c. circuit breaker caused it to stick, and in the others the time-limit fuses on the high-pressure overload gear were accidentally omitted. On all other occasions the flash-over has been cleared without the machine dropping out of step, or local flashing only has occurred which has not developed into a flash-over. I should like to ask the author what is the real significance of "average voltage per bar." It appears to me to be too arbitrary a figure to be treated as a definite basis for arriving at the table of maximum voltages at various periodicities given in the paper, although I do not suggest that the table may not in its results represent the actual limit of design at the present time. The average voltage per bar can be only a figure of merit, since, if considering the possibility of spontaneous jumping across from bar to bar, the important thing would be the maximum voltage occurring approximately midway between brushes, which will probably be of the order of 40 per cent in excess of the average. Personally, I am rather inclined to doubt the likelihood of this spontaneous jumping, with a voltage of 40 per cent in excess of the average figures given by the author. On the other hand, the voltage per bar has a zero value under the brush in normal circumstances, but a heavy load or short-circuit displaces the zero. For a given displacement, the voltage per bar under the brush will depend upon the steepness of the curve. The "average volts per bar" is a rough indication of this steepness and, whilst again not representing the actual voltage with which we are concerned, it may be taken as a figure of merit. I should have thought, however, that questions of angular embrace of the main pole, the shape of the pole-tips and the length of the main and commutating pole air-gaps, would have had an even greater influence on the slope of the bar-voltage curve. Perhaps the author would say whether, in referring to "average volts per bar," designers really have in mind as the danger point the maximum value or the small value near the brush, or both. In a recent number of the *General Electric Review* there is a reference to the construction of rotary converters with commutating poles without iron cores. Can the author give any details about this development? From the point of view of avoiding flash-over it would appear to be a substantial advance, but probably there are counterbalancing disadvantages in the scheme. A few years ago a series of short-circuit tests were carried out on a 1 500-volt, 800-kW set consisting of two 750-volt, 400-kW rotary converters of ordinary design connected in series. In every case where a flash-over occurred it apparently took place from the positive metal of the positive machine to the pedestal or bedplate (1 500 volts) and there was no evidence whatever of flash-overs from brush to brush on the positive machine, or of flash-overs of any sort on the negative machine (750 volts). The short-circuits included a resistance of about $\frac{1}{2}$ ohm. The peculiar feature of these tests, in which they differ from any others which I have seen published, was that the oscillograph shunt was connected in the lead between the negative brush and the negative busbar and, as the bedplates of both machines were earthed to the negative busbar, the whole of the flash-over current between brush-arm or commutator and pedestal or bedplate passed through the shunt of the oscillograph. A complete record, not only of the short-circuit current, but also of the flash-over, was thus obtained. From Fig. D it will be seen: (*a*) That the

maximum flash-over current was of the order of 3 times the short-circuit current (although it struck through about 15 inches of air space); (*b*) that the flash-over did not commence until the short-circuit current had been reduced to zero or thereabouts; and (*c*) that the current value during the short-circuit was only sufficient to reduce the terminal voltage 10 or 15 per cent. Low terminal voltage is therefore hardly an explanation of the delay in the flash-over. I believe that, although not always the case, this is typical of a very large number of flash-overs, viz. that they take place after the final breaking of the short-circuit. Before a flash-over can take place through a long air-path, a certain quantity of conducting gas has presumably to be generated by heavy sparking or local flashing lasting for an appreciable time. It is probable that in the case of relatively high-resistance short-circuits this local flashing is less intense during the period up to point (*a*), whilst the short-circuit current (about 5 times full load) is sustained, than it is later between points (*a*) and (*b*) when the current is decreasing, due to the flux in the commutating pole not being able to die away as quickly as the current. Under

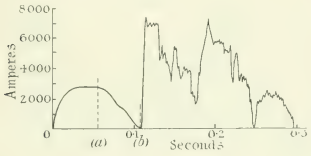


FIG. D.

much heavier short-circuit conditions sufficient gas would probably be generated earlier, and the flash-over would be more likely to occur before point (*b*) is reached. Short-circuits on a railway system are mainly due to faults on the rolling stock or track equipment which, in accordance with the ordinary laws of chance, occur only occasionally in the immediate vicinity of the sub-station. Consequently a large proportion of the short-circuits met with in practice are not of the heaviest type, although probably the average case is somewhat more severe than in the tests cited above. The resistance of the air path immediately before the flash-over strikes is of such a low order that even a layer of ordinary paint acts as an appreciable deterrent. Flash-overs to the pedestal or bedplate generally strike parts where bare metal is exposed, even when this considerably increases the length of the path. This is a common experience in practice and was well illustrated in the particular tests referred to. Another sort of flash-over is met with in practice, where a machine carrying a load which is getting near the limit of satisfactory commutation, has the circuit breaker tripped and a flash-over follows although no short-circuit has occurred. These phenomena suggest that it is quite as important to consider the way in which load or a short-circuit is taken off a machine as it is to limit the time of the short-circuit by a high-speed breaker. It seems that what is really required is a breaker which, whilst starting to operate as quickly as possible (thereby possibly preventing the maximum short-circuit value being reached, but in any case allowing the high value to continue for as short a time as possible), shall have some lag introduced in the final break. In other words, it appears that a powerful magnetic blow-out on the circuit breaker is out of place and may do more harm than good. The use of a diverting resistance across a high-speed circuit breaker tends in the right direction by reducing the current in two steps, but it is doubtful whether satisfactory values can be obtained in two steps to suit all conditions, and it appears to me that a design of circuit breaker should be produced with a continuously variable resistance. I think that the conception of a flash-over being a development of an arc drawn out from bar to bar and finally reaching from brush to brush is misleading. I believe that in many, if not most, cases, brush-to-brush flash-overs jump across spontaneously, clear of the commutator, through conducting gas formed by previous local flashing which itself does not extend more than a few inches from the brushes. Flash-overs to bedplate or pedestal must in any case be of this type. If this is typical of the formation of flash-overs in general, there is then no direct connection between the time which a high-speed breaker takes to open and the time which a commutator bar takes to travel between brushes of opposite polarity, although the contrary is frequently stated. The author has given a very full analysis of the causes of ripples. This is a matter of great importance concerning which little information has, to the best of my knowledge, been previously available.

Mr. E. Fawssett: I am much interested in the curves showing ripples in rotary voltages which, however, appear to be obtained by an oscillograph with simple resistance connection to the circuit. We have used a method on similar tests enabling a much smaller percentage ripple to be determined with accuracy. One cannot much overrun the strip or mechanically suppress the zero, and a total amplitude of ripple of 1 per cent of the impressed volts would show on a Duddell falling-plate outfit as only 0·7 mm with a simple resistance connection, zero and full voltage being the width of the plate apart, say 70 mm; i.e. with a 700-volt circuit we should get a sensitivity of 10 volts per mm. We can, however, electrically suppress the zero by employing a back E.M.F. which may almost balance the applied voltage. Thus in the above case if a battery of 630 volts be applied in opposition, the balance of 70 volts may be arranged to give the full deflection, or a sensitivity of 1 volt per mm, i.e. 10 times as great. There is no great difficulty in using such a battery, as even pocket-lamp primary cells can be employed, the maximum current required being 0·1 ampere, if precautions are taken to read the open-circuit voltage and allow for their internal resistance. Since, however, it is the current that causes the disturbances to telephones and the like, its characteristics may be more readily examined and with as good sensitivity, provided that the current output can be kept reasonably steady while the adjustments are

made and the plate dropped. The main current traverses a high-drop shunt, such as a feeder resistance, giving, say, 10 volts, this potential difference being

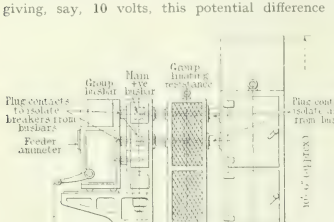


FIG. E.—Arrangement for high-speed diverter, limiting resistance and low-speed circuit breakers.

made in this direction, particularly for railway electrification where it is to be assumed that short-circuit conditions will be exceptionally "severe" owing to the large amount of power to be controlled. A circuit breaker for this purpose with an electromagnetic balance for high-speed operation has been constructed by my company (see Figs. E and F). In the main it consists of two electromagnets normally attracting a common armature, but in opposite directions. One is energized by a series current and the other by potential. The circuit breaker is closed by the latter and opened by excess current in the former. The current-operating coils and core are comparatively large, thus creating a very strong field which gives high speed of mechanical movement and an intense magnetic blow-out. Moreover, the reactance thereby introduced is sufficient to reduce the rate at which the machines build up on short-circuit, thus giving more time for the breaker to function well in its efforts to prevent the current reaching the maximum. The next object is to restore the circuit steadily to normal. This is accomplished by shunting the short-circuit current

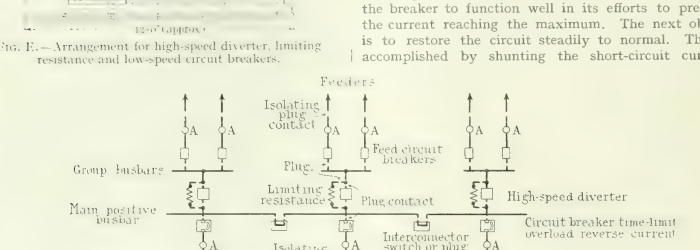


FIG. F.—Diagram of connections for the arrangement shown in Fig. E.

opposed by a 10-volt secondary battery in series with the oscillograph strip. Any convenient degree of sensitivity is obtainable in this way and the full width of plate may readily correspond to 1 or 2 per cent of the full direct current, certain precautions being obviously necessary.

Mr. H. W. Clothier: The principle of making the plant protect itself is quite sound, as external protective apparatus, however well designed, does not usually make for simplicity. But it is noticeable that the author admits that "if the short-circuit conditions are severe the machine should be further protected by a high-speed circuit breaker." There should be no operation of switches on the high-tension a.c. side of the converting plant, and it should be possible to clear faults repeatedly with a minimum of damage to the commutator and without discontinuity of supply to the sound plant and feeders. The author does not record what switchgear will do. This omission encourages me to mention some developments recently

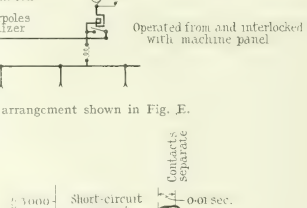


FIG. G.—Short-circuit characteristic without limiting resistance; showing speed of operation of circuit breaker.

through a resistance until the track feeder circuit breaker, preferably of a low-speed carbon-break type, clears and isolates the fault. Then the high-speed

switch is automatically closed again and the system is ready for the next short-circuit. Fig. G shows a time test for the mechanical lag and magnetic blow-out of the arc respectively, when operating on a short-circuit without the shunted resistance. Fig. H shows a characteristic short-circuit of a machine. The curve is similar in shape to those illustrated by the author in Figs. 4 and 11 (except that the author's graphs read from right to left). The lower curve, based upon the above and other oscillogram records of short-circuit, indicates how the rise and decline of short-circuit current may be controlled, in respect of both time and amplitude. Cutting off the short-circuit current at approximately one-third its maximum value, and grading the restoration of the circuit to

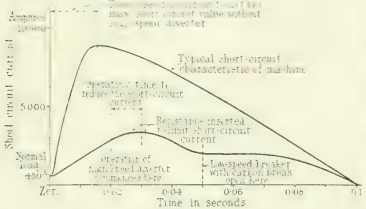


FIG. H.—Diagram showing the principle underlying the use of a "Reyrolle" reactance-type circuit diverter employing a limiting resistance protecting a rotary converter against flashing when subject to short-circuit conditions.

normal, must necessarily considerably reduce the heat expended at the brushes, and thereby the flashing and consequent damage to the commutator and brushgear.

Mr. F. P. Whitaker (*in reply*): With reference to Mr. Dalton's remarks, rotary converters are capable of taking care of regenerative braking. It is necessary to arrange the machines so that the series magnetization is reversed as the load passes through zero. This can be done by designing rotary converters with two series windings (one for use when the machine is converting alternating current to direct current, and the other for use when the conversion is from direct to alternating current), and by equipping the set with a reverse-current relay and a contactor for short-circuiting one of the series windings.

In reply to Mr. Townend we have found the fan very effective on short-circuits, especially for the prevention of restriking; conditions can be further improved by means of the blow-out, as this sweeps the arc off the surface more rapidly and effectively prevents a flash occurring on the commutator surface. If a flash occurs it is round the end of the commutator away from the running surface, which is left clean and free from damage. There is good reason to believe that, in the near future, machines will be constructed free from flash-over, even when protected by the ordinary type of breaker.

With regard to Mr. Sykes's remarks, a duplicate series of tests were taken with a high-speed breaker and an ordinary type of circuit breaker. The short-circuit current with the high-speed breaker generally started to decrease within 0·01 second after the instant of short-circuit. With the ordinary circuit breaker the current did not start to decrease before 0·06 to 0·08 second. The arc was quenched on the high-speed breaker in about 0·01 second, whereas the current was not completely broken on the low-speed breaker in less than one-sixth of a second. No doubt the reduction of time during which a short-circuit is on the machine is important, and, when considering the ordinary type of breaker, those which operate relatively slowly should be avoided.

In reply to Mr. Beard the efficiency curves given include the losses in the transformers. I have known of one or two cases of interference by the tooth ripple from traction motors, but generally the conditions of design of d.c. traction motors do not lead to tooth ripples.

The average voltage per bar is, as Mr. Poynder points out, purely an arbitrary figure, but a very useful one, inasmuch as its value is absolute and does not depend on calculations, including factors of doubtful value. Undoubtedly a machine in reasonably good condition would not spontaneously flash when the maximum volts per bar are 40 per cent in excess of the limits given in the paper, but, owing to armature reaction, much higher values can be obtained with rapidly varying loads or under short-circuit conditions, and it is such conditions which really limit the maximum volts per bar and, in turn, the average volts per bar. I do not think that the ratio of maximum volts to average volts per bar varies very much on machines of established makers. It is advantageous to increase the reluctance of the commutating flux path, but in my opinion it will not become general to omit the iron of the commutating pole on rotary converters. Mr. Poynder's description of the types of flash-over is instructive, and, no doubt, a flash-over may be spontaneous or due to the production of conducting vapour while the machine is carrying the short-circuit current. From all the tests I have taken it would appear that, if the average voltage per bar is reasonably low and the machine well designed from other points of view, flash-over is generally the result of the production of conducting vapour produced by bad commutation of the short-circuit current; in such cases the machine flashes when the short-circuit is disconnected from the machine and the terminal voltage of the machine rises. On partial short-circuits, the d.c. voltage is maintained long enough to produce a flash so soon as sufficient vapour is formed. The second type of flash-over cited by Mr. Poynder is more likely to be spontaneous due to high voltage per bar produced by unbalanced armature reaction. The higher the average voltage per bar, the more likely is this to occur. The ideal type of high-speed breaker is undoubtedly one without a shunt resistance, and I think this will be the final design, but it must not rupture the arc too quickly.

Mr. Fawssett's remarks are instructive, especially as I know that he has done useful work in connection with the measurement of ripples.

Mr. Clothier's remarks are also interesting in showing the lines along which development is taking place.

I am not very clear in regard to Fig. H, but it would seem that Mr. Clothier rather expects the rate of rise of the short-circuit current with the high-speed breaker to be only a fraction of the value that would exist with the ordinary type of low-speed breaker. I doubt whether the introduction of the high-speed breaker would materially change the rate of increase of the short-circuit current. In some cases, if the breaker is well designed and adjusted, it will open the circuit before the current has reached its final value. I understand that the lower curve to which I refer was not actually measured but was calculated.

Scottish Centre, at Glasgow, 11 April, 1922.

Mr. G. G. Braid: The paper is of great importance to all electrical engineers interested in electric traction. The conditions under which rotary converters operate when supplying a traction load are much more severe than those for an ordinary lighting and power load. Not only are there large temporary overloads, but short-circuits are frequent. As regards overload, rotary converters supplying power to some of the underground railways in London have to withstand a 300 per cent overload when the trains are starting. As regards short-circuit, a few years ago I was in a station which was supplying power to a surface contact system of tramways and, judging by the number of times that the breaker of the rotary converter which was supplying the load opened during the comparatively short time that I was in the station, I should say that short-circuits occurred on an average 100 times a day. The Glasgow Tramways Department have had some little experience with ripples. Shortly after the system was started up, about 22 years ago, on applying the oscillograph to the direct-current supply voltage from the rotary converters it was found that there was a considerable ripple amounting to between 30 and 40 volts, the supply being about 550 volts. It was soon found that this ripple did not originate in the converters themselves but in the generators. The wave-form of the alternators was found to possess an 11th and a 13th harmonic which, under certain arrangements of cables, could be made to give a partial resonance. It was these harmonics which produced the comparatively large ripple on the converters. When the old low-speed alternators were replaced by modern high-speed turbo-alternators designed so as to give a nearly pure sine wave-form, these large ripples disappeared. The ripples due to the rotary converters themselves are of a very small order, i.e. not more than 1 per cent of the supply voltage. When they were magnified they were found to consist of 6 large ripples per period, on which were superimposed 6 smaller ripples, i.e. 36 small ripples per period, or 18 and 108 large and small ripples respectively per revolution of the rotary-converter armature. The larger ripples seem to arise from the method of connecting the slip-rings to the armature. The smaller ripples are the tooth ripples, there being 108 slots in the armature core. By careful design and special methods of construction, no ripples greater than one-half of 1 per cent of the d.c. voltage need be produced. I should like to know the author's opinion of the exact cause of the larger ripples, and as to how they might be diminished. A number of engineers recommend mercury-vapour rectifiers instead of rotary converters for traction purposes. Surely the ripples from these rectifiers would be much larger than those from a well-designed rotary converter.

Mr. A. P. Robertson: In Fig. 1 the author shows two rotary converters connected to one transformer with two secondary windings. The reason that these machines ran so well together is possibly due to interconnection of the armature and the field connections. The author mentions commutator speeds of about 8 000 ft. per minute. I suppose that commutators for that speed would require to be banded to keep them together. Later in the paper it is shown that it is necessary to have an auxiliary to the machine, consisting of a high-speed circuit breaker. The lantern slides shown confirm that it is a great advantage if the machine can be kept in circuit on the a.c. side after a flash-over, because then it is very much quicker to get under way again, or rather because the number of short-circuits and flash-overs is not so great. That of course applies very much more to traction work than to public lighting and power supply. If the commutator can be kept clean, then it is a great advantage if the machine can be kept running so as to enable it to be put back on the busbars. This has been done even when a machine has been slightly scorched. The circuit breaker should therefore be extremely rapid in action. I should like to ask the author what is the speed of opening of the circuit breaker which he showed. His magnetic blow-out certainly performs its purpose very efficiently.

Mr. A. E. McColl: The author is inclined to suggest, perhaps rather definitely, that future electrification may be on the lines of 1 500 to 2 000 volts d.c., but I am of the opinion that no such voltage represents the final solution of the main-line electrification problem. The capable engineers of the Swiss Government have committed themselves definitely to a.c. working, and I think that experience will fully justify their choice. If d.c. working is adopted and the drawbar gear on British railways is increased we may have locomotives capable of dealing with over 2 000 kW. The collecting and transmission systems for main-line locomotives dealing with powers of this magnitude become cumbersome, and for this reason primarily I would say that d.c. electrification at 1 500–2 000 volts does not represent the final solution of the problem. The author has designed a rotary converter which is capable of dealing with very large overloads and the heavy, recurring short-circuits that may arise in traction working. Circuit breakers have been developed in America for dealing with the large currents which may be expected from these machines. Mr. Robertson asked at what speed these circuit breakers operate. I think that 1/200 second is their maximum speed, and

I should like the author to confirm this. I am very interested in the author's explanation that the amount of copper vapour around the commutator after a short-circuit is a function of the circuit-breaker speed. I understand that these high-speed circuit breakers are large and costly and this may possibly limit their application in connection with traction substations. As regards the protection of d.c. converting apparatus I suggest that there are other means which have not yet been adequately investigated. I should like to ask the author if he has had any experience of the benefits of reactance in circuit with the d.c. side of large rotary converters. To those who have had experience of railway and tramway working on a large scale, it is a common experience that no selective action is obtained with circuit breakers for faults which occur fairly close to the substation. For example, a fault occurs on a car and opens simultaneously not only the circuit breaker controlling the section with a possible setting of 1 500 amperes but also the breakers of several rotary converters which may have an aggregate setting of 20 000 amperes. The cause of this is obvious and lies in the fact that the time-constant of the circuit is too small. If the time-constant can be increased so that the growth of the current to its maximum value is delayed for, say, 1 second, we obtain proper selective action for the various circuit breakers, and the production of copper vapour, on which the author lays so much stress, would be effectively reduced. At present we install on a.c. systems large and costly reactors for current-limiting purposes, and I should like to know if reactors on similar lines have been considered for large d.c. supplies, and what time-constant may be expected for a reactance of reasonable dimensions. Regarding the question of ripples, some years ago I was concerned in an investigation on two rotary converters in this neighbourhood, of the author's design. These gave a very loud musical note which made speech practically impossible on the Post Office telephone lines throughout a considerable portion of Dumbartonshire. After some experiments, however, we traced it to the tooth ripple of the converters. In the early days of electric traction in Glasgow we had, in the power house at Pinkston, low-speed alternators which gave a very pronounced 11th harmonic. This harmonic came right through the step-down transformers and rotary converters and appeared on the d.c. voltage in the form of a ripple having a variation of 12 volts R.M.S. With the advent of the turbo-alternator, however, this completely disappeared, and with rotary converters built in 1900 no telephone troubles were experienced due to the normal ripple of the machine. On outlying tramway lines with an infrequent service the tooth ripple of the car motors was more troublesome.

Mr. G. M. S. Sichel : One of the limiting factors, probably the limiting factor, in commutating machines is commutation. There is nothing that gives the operating staff more confidence than a machine which commutates well, and to an equal extent there is nothing which creates a feeling of greater unrest and apprehension than a machine sparking continuously and liable to flash over at any moment. With machines working on a steady town load the case is comparatively simple, because the machine has to deal only with momentary short-circuits, and in a well-designed cable system these are of relatively infrequent occurrence ; the problem is, however, very different in rotary-converter substations dealing with a traction load. Those who have had any experience of operating rotary converters on fluctuating loads, will no doubt have appreciated the necessity of having the commutating poles adjusted so as to give, as far as possible, sparkless commutation on all loads. This is possible only when the commutating-pole winding is not shunted by a diverter of the ordinary type. With a highly inductive circuit shunted by a non-inductive diverter, then, so long as current values remain steady, commutation is good ; when, however, a rush of current takes place due to a traction peak or other cause, the current takes the easier path through the non-inductive diverter, with the result that a state of unbalance is set up between the armature and commutating pole fluxes, and bad commutation results. It is a curious fact that some rotary converters will not run unless a diverter is placed across the commutating pole winding, and I believe that the author's firm went to a considerable amount of trouble with some converter sets about 6 or 7 years ago, in endeavouring to get these machines to run without a commutating-pole diverter, as they were feeding a traction system with heavy peaks. Although a great deal of work was done and much trouble taken to try to achieve this object, I believe that in the end they were compelled to put a diverter across the commutating pole winding. If the author can give the final result of the experiments it would add to the value of the paper. Another point which is not often appreciated in connection with commutation troubles on rotary converters is that frequently the cause of poor commutation does not lie in the rotary converter itself but is due to some defect in the design of the transformer which feeds it. A large amount of time and trouble has been spent in the past on machines which would not commutate satisfactorily ; various grades of brush have been tried, modifications to the brushgear, variations of the commutating pole and main pole air-gaps, etc., but they produced little or no improvement, the cause eventually being discovered, by means of oscillograph tests, in the transformer. I should like to ask the author whether a six-phase rotary converter fed from a two-phase high-tension supply through a Scott-connected bank of transformers has any predisposition towards commutation troubles and liability to flash over. In one case which has come to my notice of two rotary converters supplied through Scott-connected transformers, there is a great liability to flash over at the d.c. brushes at the least disturbance on the d.c. traction system. Is there anything in such a system which tends to produce commutation instability ? In the American technical journals a year or two ago there were some articles dealing with some device for producing a short-circuit at the slip-ring connections of a rotary converter in case an excessive overload was thrown on the d.c. side of the machine. In other words, in a traction system, if a short-circuit came on, circuit breakers of the contactor type were instantaneously closed across

the slip-rings in such a manner as to short-circuit the low-tension side of the transformer through reactances, which cut down the current in the transformer and allowed the arc, which might develop on the d.c. end of the rotary converter, to clear and also allowed the vapour developing under heavy-current conditions to get away from the machine. When conditions were again steady, these contactors opened and re-established the supply. Has the author any information with regard to the success or otherwise of this arrangement? Although the author has obtained good results on his machines, I think that the idea that from 4 to 10 times the normal current can be taken from a converter should not be encouraged. For instance, a user might put one machine on the bars when he ought to put two, and thus the severity of the conditions under which the machine has to work would be increased, and also the supply would be liable to interruption.

Mr. W. J. Belsey: The author has brought out very clearly the fact that the machine must be designed for the particular duties which it has to perform. The ordinary standard industrial motor has been developed on the lines of a compromise not unduly expensive so as to retard its installation, and, on the other hand, not unduly cheap on account of maintenance. When the motor is applied to another class of service, say traction work, an entirely different set of conditions arises and the motor has to be specially designed to meet these, and has to be made specially robust in certain particulars. The same applies to rolling-mill work. In applying the rotary converter for 1 500-volt traction purposes, it follows that the design and construction must be altered in various ways to meet the new conditions which will inevitably arise. It is well for manufacturers, when extending the application of any piece of apparatus, to examine carefully any weakness or possible defect which might show itself, due to the more exacting requirements of the new application, and the paper appears to me to be useful in showing what developments are taking place, with a view to ensuring a satisfactory service in the new conditions.

Mr. J. Anderson: The mechanical efficiency of rotary converters is a subject which lies very near to my own particular line of investigation, and in this connection I should like to say a few words on the question of the application of anti-friction bearings to electrical machinery. I had in mind the case of a large rotary converter, the capacity of which is 2 000 kW, and the speed 1 000 r.p.m., rising to 1 200 r.p.m. This machine is, I understand, being fitted with roller bearings, and I should be glad if the author could say what the expected increase of efficiency will be and generally the reduction in maintenance charges and other charges in connection with the running of a rotary converter of that size. Mr. Belsey mentioned that a machine had to be designed for the job to which it was to be put, and it seems to me that nowadays we have to consider very closely what we are going to do to reduce costs. It is all very well to say that we have a certain electrical efficiency, but if we are throwing that away on other parts of our machine I think that we ought to consider whether we cannot eliminate some of these losses. Even in the smallest machine I feel sure that there are certain losses which can be avoided by carefully considering the various problems which until now have not been seriously attacked. Amongst these are, I think, the friction of bearings, the lubrication used, the time taken in lubricating journals and, finally, the repair of these journals. I should like to have the author's views on these matters.

Mr. G. Henderson: The firm with which I am connected is in a very favourable position in regard to this class of work, as they are the only manufacturers in this country of all types of rotating converting machinery, viz. motor converters, rotary converters and motor-generators and they are therefore able, due to their past experience, to say which type is the most suitable for high-voltage d.c. railway work. On page 501 the author says that the converting apparatus should possess certain characteristics, and he puts efficiency first. I think that reliability should take first place, especially if automatic operation is to be considered. On 50-period rotary converters I agree with the author that the average voltage between commutator segments should be kept as low as possible, but this may give an unsatisfactory design in other respects and a higher figure than 13 volts may have to be used. With regard to commutator speeds, if reliability has to be the first consideration I consider that with axial commutators 6 000 ft. per minute is high enough. On page 502 the author gives a table of maximum d.c. voltage with a single-commutator rotary converter, which shows that for 1 500 volts, 50 periods, two 750-volt machines in series are required, and at the same time he mentions that a single-unit motor converter could be used for the same service. What does the author consider to be the advantage of two 750-volt rotary converters in series over a single 1 500-volt motor converter? Apart from such advantages as a single unit instead of two separate machines, less floor space and great reliability, the design of a 50-period motor converter on the d.c. side is similar to that of a 1 500-volt, 25-period rotary converter, which is acknowledged to be a more satisfactory machine than a 50-period rotary converter under the same conditions, with the additional advantage that with a motor converter, operating partly as a d.c. generator, the chances of a flash-over on short-circuit are smaller, owing to the ratio of commutating-pole ampere-turns to armature ampere-turns being greater. The addition of a compensating winding is also possible, and this means that the average voltage between commutator segments can be higher in a motor converter. It is well known from long experience that, on 600-volt railway service, standard motor converters give every satisfaction on high overloads and short-circuit. Again, for 3 000 volts d.c. the author on page 502 says that a synchronous motor-generator set, with two 1 500-volt d.c. generators in series, is the most serviceable unit. Surely in this case the obvious advantages of two 1 500-volt d.c. motor converters in series rule the motor-generator out of consideration on efficiency alone, if for no other reason. It is unnecessary for me to go into detail regarding the general performance of the motor converter, because for 1 500-volt working it is the same as for low d.c. voltage motor converters, and the mechanical

construction of the d.c. side is the same as that for any high-voltage d.c. generator or 25-period rotary converter. Advantage can be taken of high-speed circuit breakers if necessary, and automatic operation presents no difficulties with motor-converter installations.

Mr. A. C. Stewart: My experience of the old 3-pole rotary converter without interpoles showed that perfect commutation was obtained. Such results are not secured with the modern machine, and I should like to hear the author's opinion as to whether commutation without interpoles could not be obtained under present-day conditions.

Mr. D. M. Buist (*communicated*): I should like to ask the author why he has attacked the problem of flashing-over from the point of view of protection rather than from that of prevention. For this trouble prevention is better than cure, and it seems to me that the author's aim has been the reverse, in that the employment of shields, fans and blow-out coils is more of the nature of a cure for, rather than a prevention of, flashing-over. Accepting for the present that 1 500 volts d.c. will probably be the standard pressure on main-line electrification, and disregarding for the moment the rivals of the rotary converter for conversion purposes, viz. the synchronous motor-generator so favoured in America, the La Cour converter and the more recent mercury-arc rectifier, the problem then becomes how best to modify the present design of rotary converters so as to provide successful operation of a single-commutator machine at this high voltage, from the points of view of efficiency, power factor, voltage regulation and immunity from flashing-over. The author himself agrees that it would be sound practice to consider the design first, and I contend that only after having gone as far as possible in this direction should external preventive measures be considered, e.g. high-speed circuit breakers, blow-out coils, fans and shields. Again, the rotary converter in relation to its feeders, under short-circuit conditions, should be considered. Dealing first with design, sparking, both at the bushes and more especially across intermediate segments, is usually the forerunner of a flash-over, and both may be traced to the distortion of the field by armature reaction, the effects of which are more complicated in a rotary converter than in the ordinary d.c. generator. The neutralization between the a.c. and d.c. armature fields is only partial at all times and very unstable, and is not maintained at overloads approaching short-circuit. The consequent distortion then becomes so great that excessive sparking occurs as a result of the increased reactance voltage induced in the coils undergoing commutation. As a remedy for this, interpoles are only partially successful, because, owing to space difficulties, the unavoidable insufficiency of iron gives too concentrated a commutating field in the interpolar space. Moreover, to allow for the rotary converter running on the a.c. side only, after the d.c. side has tripped out, the ampere-turns of the rotary-converter interpole should, strictly speaking, not only provide a commutating field, but also neutralize the total a.c. reaction field, otherwise the latter will lead to a flash-over, even with the d.c. side cleared, an occurrence to which the author himself refers on page 504. To achieve complete immunity from flash-over by altering the design is, unfortunately, an aim more ideal than practical, as experience has so far shown, but I am still of the opinion that the solution will be found in a thorough study of the effects of armature reaction upon the field distribution under overload and short-circuit conditions. So far as external protective measures are concerned it would be interesting if a comparison could be made between the devices advocated and tried by the author, and the high-speed circuit breaker operating in, say, 1/1 000 second, from the points of view of efficiency and cost. Certainly the results obtained by the author, especially with blow-out coils, are excellent, but I am in favour of preventive measures external to the machine altogether. As regards the feeders, the position of the tapping point is very important, and worthy of more consideration than seems to be given to it. Short-circuits on those portions of the line fed by the shortest feeders are invariably more frequent and disastrous in effect than those on the longer feeders, from which it seems reasonable to infer that the longer the length of the feeder, the less frequent will be the flash-overs, owing to the increased resistance and inductance of the short-circuited circuit.

Mr. F. P. Whitaker (*in reply*): The transference of ripples from the a.c. to the d.c. system mentioned by Mr. Braid is of interest, as it is one of the first cases on record. Oscillations having a frequency of six times the normal might result from any of the various causes set forth in the paper, and it would be impossible, without investigation, to state which cause was predominant. The undulations from a six-phase rectifier would undoubtedly be greater than on a rotary converter equipment.

In reply to Mr. Robertson, commutator speeds of 8 000 ft. per minute are easily obtainable with the ordinary type of commutator. It would certainly be disadvantageous to use either banded or shrunk-ring construction on such machines. The high-speed breaker used for the tests illustrated in the photographs shown during the discussion, started to open the circuit in approximately 0·01 second. The low-speed breaker started to open the circuit in 0·06 to 0·08 second.

With reference to Mr. McColl's remarks, the paper was not intended to be an introduction to the merits of alternating or direct-current systems of electrification, but I think we should not conclude that, because the Swiss engineers have decided that the a.c. system is best for their country, British engineers are wrong in coming to any other conclusion for our country; in fact, it would be surprising if the conditions in all countries were the same, and I have confidence that our own engineers will finally come to a correct conclusion. The high-speed breaker can be made to commence opening in about 0·005 second, but, as previously mentioned, the time of opening was about 0·01 second during the tests illustrated in the discussion. I think that the limitation of d.c. short-circuits by means of reactance will be found to be costly and cumbersome. It has been investigated at various periods and found to be uneconomical.

I think that the machine referred to by Mr.

Sichel was installed some 9 years ago. It was found that it would not take the very sudden changes of load without intermittent sparking unless the diverter was fitted across the commutating poles. The fitting of the diverter really increased the damping of the machine and, for this reason, improved the general operating conditions. It has always been our standard practice to adjust the commutating poles of rotary converters without the use of diverters, but in the early days of commutating-pole machines this condition did seem to present difficulties, which, however, were finally and easily remedied. I believe that the company with which I am associated was the first to impress on the manufacturers of transformers the necessity of correctly designing transformers for use in conjunction with rotary converters. Even manufacturers who built both transformers and rotary converters did not seem to recognize this. We found difficulty in convincing some makers that the design of a transformer had a considerable influence on the commutation of rotary converters, but this point, I think, is now generally recognized. Scott-connected transformers are likely to give trouble unless correctly designed. In my opinion the device for short-circuiting the slip-rings of a rotary converter as soon as possible after a short-circuit was not successful. The same device, however, is more useful in connection with motor-generator sets, and has a limited use in this direction. This device has been described by other contributors to the discussion.

In reply to Mr. Anderson I do not think that the efficiency of the modern rotary converter would be improved by more than 0·15 per cent if fitted with ball bearings. I have not had very much experience with the maintenance of ball bearings on rotary converters. Some sets were installed many years ago which did not run successfully, and I am afraid rather prejudiced the position of ball bearings for rotary converters. The ball bearings were eventually replaced with roller bearings and these have given satisfaction, although the preference is for the ordinary type of bearing.

I agree with Mr. Henderson that the motor converter presents an easier proposition for the generation of 1 500 volts in a single commutator with 50-period supply than a single-armature rotary converter, but the cost of a motor converter is approximately equal to that of a transformer and rotary equipment (either single-armature or two armatures in series), and in the case of railway electrification the voltage of supply will in many cases be higher than can be directly applied to the motor converter, so that the extra expense of transformers and an increased loss will result with motor converter installations. It would seem that we cannot get all the good qualities grouped into one machine. I think that, for systems working with 3 000 volts to earth, it will be found preferable completely to isolate the a.c. side from the d.c. side and to work with synchronous motor-generator sets, even though the efficiency of working will be lower.

With reference to Mr. Stewart's remarks, machines would cost very much more if satisfactory commutation were to be obtained without the use of commutating poles. Such poles have enabled the designer to improve the commutation considerably. This has resulted in the rating up of a given size of armature, and, providing this is not carried too far, it is all to the good; but if machines are over-rated, while the commutation may be perfectly satisfactory under steady conditions of load, they will not give a good account of themselves on rapidly fluctuating loads.

In reply to Mr. Buist the developments described have all been undertaken with a view to preventing flash-over; and, even though flash-over cannot be entirely eliminated, the idea was that the machine should be so constructed that there would be no resultant damage. Progress is being made all the time, and recent tests have demonstrated that it is possible to short-circuit a 1 500-volt 25-period rotary converter through an ordinary breaker without flashing, and similar tests will be pursued on 50-period machines. I believe that designers with extended experience in the design of rotary converters have eliminated as far as possible momentary disturbances of armature reaction, and it was the recognition of this which led to the consideration whether a flash could be prevented, even though these disturbances exist in the converter armature during the time a load is rapidly changing or during short-circuit conditions. In my opinion, developments in connection with the commutator and brush-gear will finally master this problem, even on 50-period working. To make the machine itself as robust as possible would seem to be the surest line of development, rather than wholly to rely on protecting a machine of a weaker type with a high-speed operating device.

THE PROVISION OF POWER FOR WIRELESS TELEGRAPHY.

By Major J. H. WHITTAKER-SWINTON, R.E. (T.F.), Associate Member.

(*Paper received 28th February, and read before the* WIRELESS SECTION, *5th April*, 1922.)

SUMMARY.

This paper has for its main objects:—

(*a*) The survey of the various forms of power at high tension which have been used in connection with continuous-wave wireless telegraphy in the early stages of the development of that system;

(*b*) An examination of present practice in experimental working in connection with transmitting sets of small power; and

(*c*) A statement as to probabilities regarding the future.

The essential requirements for producing "pure continuous waves" are set out and a description is given of successful methods, and of others.

The conclusion reached is that direct (i.e. unidirectional) current directly generated is inherently the best form of power, and that British engineers have now quite sufficient experience and data to design and construct generating machinery for large outputs at the high tension required for world communication.

The historical portion of the paper is a record of the line of progress in the provision of power for continuous-wave working, both in France and in all sections of the Army Design Department, and is typical of the state of the art at the various periods touched on.

The author has been permitted by the Army authorities to describe the latest form of apparatus for the provision of power; and taking the paper therefore as a whole, it forms a general review of the lines of progress covering the last five years.

Amongst the many electrical engineers who are members of this Institution, there are fortunately a good array of wireless experts, but there is a far greater number of amateurs, to whom, whilst wireless reception is comparatively well explored, continuous-wave transmission in detail is still a sealed subject.

The maintenance of communications in war-time with apparatus as simple, light and portable as possible, may be a matter of life and death, and the Army wireless telegraphy designers have had every possible advantage and the best apparatus placed in their hands as an aid to the production of such apparatus as is necessary to ensure the communications required.

It is not possible, in a single paper, to touch upon such questions as power for arc sets or the high power required for stations such as Carnarvon, Chelmsford, Nauen, Paris, and Bordeaux, and indeed the discussion of high-power sets might well take up two evenings, one for valve working and the second for arcs and high-frequency machines and their relative advantages and disadvantages. It is proposed, therefore, to deal only with quite small continuous-wave sets, beginning with approximately 25 watts and dealing particularly with sets under 1 kW, and only speak of larger sets utilizing one or more kilowatts because of special items of interest dealing with the subject of the purity of the continuous waves and the safety of the machinery.

The thermionic valve has enormously extended and greatly simplified the transmission side of wireless telegraphy and telephony, and the system of undamped wave transmission, or continuous-wave transmission, renders it possible to give good signals for something of the order of 1 watt per mile up to a limit of some hundreds of miles, and very small transmitting sets are now in vogue.

The author is far from advocating such a rough rule for other than quite small sets, and, in helping to determine power sets for semi-commercial use and distances of 500 miles or over, has persistently advocated the use of much higher power. Nevertheless, a continuous-wave transmitter utilizing approximately 3 kW at the valves and putting $1\frac{1}{2}$ kW into a 70-ft. aerial has recently communicated with a station over 1 800 miles away, and there are many instances on record of fairly regular traffic being maintained, even in countries around the Mediterranean, with continuous-wave sets using not more than 2 watts per mile, primary current, and this would of course, with transformations and general losses, mean very much less than 1 watt in the aerial for every mile covered.

The author has recently been able to apply the oscillograph to the various currents being used for continuous-wave sets and also to record the variations of amplitude of the continuous waves which the transmitter, supplied with such currents, was producing.

Some time ago, an important body dealing in some measure with the control of national and international wireless, sought for a definition of "continuous wave." The words "continuous wave" have been very loosely used and "pure continuous wave" has been called for, so that the question as to what is a pure continuous wave has been canvassed by many authorities. The author does not pretend to be able to give a critical answer to that question, but suggests that for the purposes of this paper the following will serve, namely:

> An undamped wave of unvarying amplitude and generally free from harmonic distortions.

To produce a system of wireless telegraphy employing such waves has been the aim of the Service designers, particularly during the last two years, and the production of pure continuous waves as previously defined has involved a vast amount of research work as regards (*a*) supply of power to the anodes; (*b*) supplying an unvarying filament emission, except as controlled by the oscillatory action of the transmitter; (*c*) design

of methods of using valves to avoid the production of harmonics, or, alternatively, finding means of preventing the harmonics passing into the aerial.

The author in this paper deals in particular with (*a*) and (*b*), and (*c*) will have only a passing reference.

Historical Notes.

It may be thought that some of the early apparatus illustrated or referred to might be accompanied by apologies, but the first continuous-wave set produced and used in 1916, having a very short range, probably gave out the purest possible continuous wave, the quality of which has not been surpassed.

The first single-valve set made by the Army used one valve having a heat dissipation at the anode of approximately 25 watts. The filament of this valve was heated by means of accumulators, and the anode potential was supplied by dry batteries giving 600 or 800 volts and a very few milliamperes. There was no commutator ripple, slot ripple or harmonic due to irregularities in the supply, and in some senses this might be considered to be the model for present-day practice and future attainment whilst utilizing a more powerful source of power at the higher voltages required.

If a dry battery could be produced which would give 20 to 30 milliamperes for a couple of hundred hours' key load, and batteries giving a regular potential of, say, 800 volts could be produced weighing only, say, 30 to 50 lb., such a form of high voltage would still be ideal for trench warfare and similar use. Unfortunately, the 200-volt boxes which were made up for Army use weighed 100 lb., and in a number of cases, even when they got to the observation posts and other forward stations, the batteries were found to give only a few volts or none at all, and in the best of cases they were found to be discharged after a couple of days' working.

It was soon found that the German Army was passing through the same trouble and that they had evolved what is known as the "Adnil vibrator." One of these vibrators was captured and the British Army quickly produced good working models for the Signal Service. This vibrator (Slide 1) * is merely a device which is tuned to make and break the direct current flowing from a battery through the primary windings at the moment when, by reason of the natural inductive period of the circuit, the break can be made with least sparking. Slide 1A shows voltage and current curves from an Adnil vibrator. When breaking the flow through one primary coil, the contact causes the current to pass through the other coil in the reverse direction, the intention being to produce alternating or pulsating currents at high potential in a secondary circuit by means of the pulsating current flowing in the primary circuit. With suitable condensers and carefully chosen and well-balanced vibrators, it is possible to get these things to work for hours and days together without trouble and to obtain, say, 50 milliamperes at 1 000 volts after the secondary current has been passed through the rectifying valves, but as the instrument was undoubtedly only a laboratory instrument and certainly not fit for field use, the unknown and careworn warriors deserved very much more credit for their wireless signals with such apparatus than they ever obtained.

Early in 1918, the vibratory unit 100 watts was issued (Slide 2). This included two rectifying valves, one for each half-period, and the total consumption was about 6 amperes at 20 volts, and 3 amperes at 6 volts, that is, about 140 watts, and as the output was 50 mA at 1 000 volts (d.c.), the efficiency was about $33\frac{1}{3}$ per cent, a very creditable performance for a laboratory instrument. Further, as the frequency was very high and the condenser large, practically pure continuous waves were probably again produced.

Prior to the production of this apparatus and subsequent thereto, simple induction coils were employed to produce high voltage for the transmitting anodes, and very good service indeed in the early days was secured from such apparatus. It did not give pure continuous waves, but interrupted continuous waves or "tonic train," and for short ranges such apparatus was preferred, as it was not necessary to heterodyne, and by tuning the vibratory plates of the induction coil each station could have more or less a distinctive note. Wherever only a few stations are working, interrupted continuous waves are still permissible and practicable, but it is not possible to get anything like such sharp tuning with any form of interrupted continuous waves as when pure continuous waves, which must be heterodyned, are employed, and as soon as anything like congested working arose there was an intensive demand for real continuous waves.

As soon as radio-telephony was demanded, particularly for the Air Service, wind-driven d.c. generators giving about 600 volts were produced. The British Thomson-Houston Co., of Rugby, Mr. Mackie, of Lambeth, and Messrs. Newton Brothers, of Derby, produced early and excellent machines. Wind-driven high-tension alternators had also been in use for some time, but some period had to elapse and a considerable amount of experience to be gained, before it was realized that direct current at high tension, practically free from slot ripple and commutator ripple, was essential for pure continuous-wave working, as well as for radio-telephony, and the author believes that it was early in 1918 when the very light 1 000- to 1 500-volt machines were first made by Messrs. Newton Brothers (Slide 3).

The machine illustrated was capable of giving 100 mA at 1 200 volts when driven by a battery giving 12 volts, and the machine weighed 12 lb. This machine was specially prepared for working in the cab of gas-filled aircraft. It is a simple example of motor and dynamo construction. There were two fields, two armatures, two bearings, and the high-tension commutator had 72 bars, the diameter of the commutator being 1·75 in. The machine ran at 6 000 r.p.m. and sparkless operation was obtained; otherwise it could not have been trusted for the service of wireless communication in "lighter-than-air" aircraft.

Since 1918, this machine has become the model and forerunner of many others. Unfortunately, it was not possible to design and manufacture such machines in numbers in time for the stern work in the field before

* The photographs, which were shown at the meeting as lantern slides, cannot be reproduced satisfactorily in the *Journal*.

the Armistice, but since 1919 progress has been rapid and other and even better machines will be illustrated, or are here for inspection. These machines may almost be called commonplace to-day, although they were undreamt of five years ago; but it says very much for the calibre of British brains and workmanship when they can produce a machine weighing 22 lb. which is capable of giving an output of 120 mA at 2 500 to 3 000 volts from a single commutator of $2\frac{3}{8}$ in. diameter, and which works sparklessly when driven at 5 000 r.p.m., the efficiency being well over 60 per cent.

Before describing these machines, however, the author would like first of all to deal with other attempts to meet the crying needs of the Service, and to point out in detail some pecularities of the needs of the wireless telegraph services as regards power.

Wind-driven alternators were very early in the field. Such machines gave, in some cases directly and in others by the aid of a static transformer, 1 000 to 3 000 volts at 250, 500 or 900 periods quite easily and well, but such machines only succeeded in producing that form of interrupted continuous wave known as "tonic train." It is not, properly speaking, continuous-wave wireless telegraphy at all, but a wave having a rhythmically varying amplitude which can be picked up at moderate range without heterodyning, and which, unfortunately, is not capable of very sharp tuning. Such machines are in use mainly in the East and, in one particular instance, a machine capable of giving 500 watts of high-tension energy at 600 periods has frequently been used to maintain regular military communication up to 600 to 800 miles range. There is, however, a classic instance of one such machine having been put to work for a few brief minutes on a well-known good aerial in the heart of London. The operator was probably very proud of the 6 amperes of aerial current, but all receiving sets working within 10 miles (and probably further) of this aerial, which happened to be working on a wave within 100 metres on either side of the transmitting wave-length, were speedily jammed and their operators retired precipitately to make a raid on the much-abused Post Office telephones to demand the instant cessation of the continuous-wave set in question.

What is good enough for isolated stations in the East, or a few scattered portable field stations, is not good enough for regular traffic in the heart of a busy business centre, and far from good enough for use in the centre of the Empire, and, needless to say, this set was quickly improved and has now been made as nearly perfect as wireless designers can make it. Certain it is that, if the aerial does not swing, it is not possible to pick up such a set when one is approximately 1 per cent off its wave-length.

Other forms of tonic train have been produced, as, for instance, chopping direct current by means of a commutator and passing the interrupted current through the primary of a static transformer, the high-tension current being subsequently rectified. The most successful method of doing this is the utilization of the well-known "buffer" system employed by Mr. Hamilton Wilson in his patented Wilson spark sets. Apparatus purchased from him can be utilized immediately by the simple application of one rectifying valve, to produce excellent rectified unidirectional current. Slides will be shown of the arrangement, and an all-copper and mica commutator slip-ring addition to Mr. Wilson's motor, for supplying the alternating current for filament heating (owing to the fact that these filaments stand at the high positive potential of the unidirectional current), and also of the general arrangement of apparatus which was put together as a stand-by provisional design ready to meet emergencies should such occur before the rotary transformers were ready for Service use.

This Wilson apparatus can be used for real tonic train, and the interrupted continuous waves emitted from the valve transmitter to which it is connected are in the form of "tone trains" at a frequency determined by the speed of the motor and the number of bars on the commutator. Such interrupted continuous wave or tonic train was very much in vogue in the early days, partly because it needed no heterodyne, and for congested working it was certainly a very considerable advance on spark methods. Where simplicity of reception is still a strong point it may be wanted again, but certainly for congested working its use has had to be abandoned. The French also passed through a similar stage and produced a mechanical rectifier (Slide 4). The slide shows how the direct current is chopped into a tuned primary static transformer and commuted by a synchronous commutator so that high-tension direct current is given. It is a very practical piece of apparatus for 100 watts although too heavy for the field.

Direct-Current Machines.

On Slide 5 are shown a range of rotary transformers which have been got out for field service, varying from 40 watts to 300 watts high tension. The 40-watt machine was designed to give 700 volts mainly for telephony. The 80-watt and 150-watt machines give 1 200 to 1 500 volts and, as previously stated, the 300-watt machines give 2 500 to 3 000 volts. The average efficiency of the 80- and 150-watt machines is now 60 per cent and the designers are still concentrating on further improvement.

Slides 6 and 7 show a 1-kW rotary transformer which at present is believed to be the very best source of power for continuous waves which has been made. Its main features are given. The diameter of the high-tension commutator is 4·75 in. Slides 8 and 9 show the construction of the rotary transformers.

It will be observed in comparing these machines with the 150-watt motor-generator which was stated to have been the adopted model, that the motor-generator system has been departed from and the rotary transformer system adopted. For small machines this does not give rise to very serious objections, although there is a distinct loss in the inability with the rotary system to control the value of the high voltage produced. The reasons for the adoption of this principle are as follows:—

(1) Higher efficiency.
(2) Reduced ripple, the motoring and generating wires being in the same slot.
(3) Reduction in weight or speed, sometimes both.

It will be noted that the slots are skewed and have a very small opening, and the author is very pleased to say that an oscillogram of the high-tension voltage provided by this machine shows so nearly a straight line as not to indicate any possible lines of improvement. (Fig. 1 shows: (*e*) Motor-generator, 1 kW; (*f*), Rotary transformer, 1 kW; (*g*) & (*h*), Motor-generator and Rotary transformer, 300 W.)

This particular machine gives direct current at 3 000 volts and such machines have been driven up to 50 per cent overload in volts and amperes without any damage resulting.

The construction of machines for 5 000 volts is almost standard practice, and orders for machines to give 10 000 volts from one commutator would be accepted to-day. The author recently had the pleasure of testing a 2-kW 5 000-volt machine, the high-tension commutator of which was only 4·75 inches in diameter. The performance was so good at 5 000 volts that its designer suggested 15 minutes' run at 50 per cent overload in volts, amperes, or both. The volts were run up to 7 500 and the current reached 0·6 ampere and the 15 minutes' test was successfully accomplished without the slightest tendency to spark or flash over, although the outer circuit was frequently broken and re-made. The maximum volts per bar on such an overload test exceeded 100, although the normal working potential difference is of course lower.

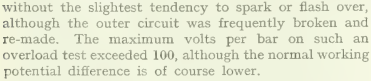


FIG. 1.

(*e*) Motor-generator, straight slots. (*f*) Rotary transformer, skewed slots. (*g*) Motor-generator, straight slots. (*h*) Rotary transformer, straight slots.

Fig. 1 (*f*) shows that there is no ripple from such machines.

As regards the purity of the continuous waves produced, providing the valves are not over-driven and when the filaments are heated from batteries, it would appear that nothing purer can be produced at present. It must, however, be borne in mind that the high-tension windings in these small machines consist of wires of very small gauge indeed; they must, therefore, be very well insulated. The practice of impregnating them into a solid mass appears to make them fairly robust, but nevertheless the system has its critics and the whole problem of the desirability of using direct current at voltages higher than round about 3 000 volts is being tested out. On the other hand the small machines up to 1 kW have certainly given satisfaction in spite of the fact that the armatures generally rotate at something of the order of 3 000 to 5 000 r.p.m. and over. When, therefore, it comes to engine-driven machines of higher power and where thicker wires are required, the author does not think there is any reason to hesitate to trust such machinery. At one time, it is true, unexplained burn-outs occurred which have been traced to ripple resonance, but this trouble has been overcome. There are, however, some engineers who naturally turn to static transformers as soon as high-voltage current is required, and the remainder of the paper will deal with the use of alternating current for both anode and filament supply.

Continuous-Wave Working from Alternating-Current Power.

In order to investigate this problem, it is necessary first to re-state the requirements.

It is well-known that unvarying amplitude of oscillatory current depends, in the case of valve sets, on:

(*a*) Purity and regularity of the current supplied to the anodes.

(*b*) Absolutely unvarying temperature of the kathode elements.

For anode high voltages there is nothing known approaching the efficiency of pure unidirectional current. The valves operate at the highest possible efficiency and the oscillatory current is freest from harmonics; the transmitting sets operate with precision and regularity and with the least possible tendency to surge or break down.

The nearest practical approach to such pure unidirectional current in commercial form is to be obtained from direct-current generators or rotary transformers, the armatures of which have many slots with small slot opening, the slots being skewed in relation to the pole-tips, the field poles designed to have a perfectly regular flux across their face, and the commutators designed to have many bars so that the commutating difference of potential is practically nil. As has been shown, such machinery can be made by British engineers, and where continuous waves obtained by the aid of such machinery gives serious trouble owing to harmonics, the fault is probably either in

(*a*) Over-driving the valves, or in

(*b*) Faulty design of the L and C values or other construction of the transmitter,

and the remedies are obvious. Wherever minor harmonics cannot be avoided, closed circuit or intermediate circuit working offers a remedy, particularly for cases of congestion due to the working of many transmitters.

The Possibility of using Alternating Currents.

From the very nature of alternating currents it is impossible for an alternating current to give a steady, continuous and unvarying positive potential to the anodes, and if the full moment-to-moment variations of potential of a sine-wave, and, worse still, a peaked wave, single-phase current at, say, 50 periods are reproduced in the variations of amplitude of the continuous wave in wireless telegraphy, the interference arising from its use can be well understood. Fig. 2, for instance, shows that the primary pressure curve has slot ripples; the secondary (3 000 V) pressure curves are much cleaner, but the variations of amplitude of the continuous waves produced appear to be further modified in shape.

It should be observed that the plate speeds of the oscillograms are practically the same and it is regretted

that the oscillogram does not give an actual picture of the continuous wave. The usual two-valve circuit was used for the two halves of the waves, and the variations of amplitude in the graphs given throughout this paper and shown on the screen can be considered only in their relation to each other. The actual value of the volts or current used to deflect the mirrors was kept similar for all photographs as far as it was possible to do so.

It is somewhat difficult to show waves of different frequencies in a relative sense, as the plate speeds cannot be controlled very well, but with single-phase currents of similar wave-form, the amplitude of the continuous wave appears to vary in a similar manner for all the frequencies tried, such as 50, 150, 250, 600. Where the alternating current is peaky, the continuous-wave variations are steeper in rising, although the

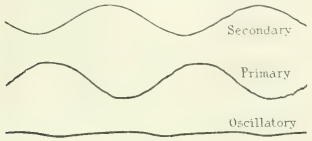


Fig. 2.

same more gradual tailing off is shown by the oscillograph used; the cause or causes it is not proposed to attempt to explore in this paper.

Rectified Alternating-Current Working.

Before going further into the question of continuous waves from alternating current directly applied, a brief reference may be made to continuous waves from alternating-current rectification methods. The use of single-phase current at about 250 periods and over is quite common practice. The primary current is stepped up by static transformers and rectified by means of two thermionic valves or other rectifiers; a reasonably large capacity condenser is used for smoothing, the value of the capacity increasing with fall of frequency, and the direct current is conducted from such smoothing and storage condensers directly to the anodes of the transmitting valves.

When the frequency of the alternating current is about 200 or over, the low-tension currents are quite suitable for heating the valve filaments, and such currents are very convenient for filament heating. The purity of the continuous waves then depends on the value of the storage and smoothing condensers, the frequency of the a.c. supply, and the steady working of the rectifiers. In Germany it is common practice to rectify by means of two-anode neon or other gas-filled tubes and, for the larger sets, two-anode mercury-vapour arc rectifiers. At Woolwich the author has experimented with what he believes to be the first three-phase high-tension tube made by the Hewittic Mercury Vapour Lamp Company (Slide 10), and has rectified three-phase currents of a potential of 5 000 volts and up to 0·5 ampere from each line to the star of the transformer. The operation on all frequencies may be considered as excellent, although for obvious reasons it is best on the higher frequencies.

At 50 periods the condensers must be very large and the wandering arc makes operators and current just a little jumpy; for large powers, however, it is certainly a thoroughly practical rectifier.

The thermionic rectifying valve is very steady in action by comparison, but is wasteful. The author knows of single-phase and three-phase, three-valve rectifiers where there is a drop in volts of from 12 to 15 per cent across the valves, besides the large filament wattage required. The neon valve is less wasteful, indeed it is even very economical, but its life is short. The relative operating lives of valves are: mercury—some thousands of hours; thermionic—300 to 800 hours; neon—30 to 200 hours. The efficiency of mercury and neon rectifiers is much higher than that of the thermionic valve. More will be said later as to the frequency of the alternating current used for filament heating, but when the frequency is 200 or over and the general design of transmitter is good, the purity of the continuous waves produced by alternating current in the above manner is assured.

With the growth of the number of wireless transmitting stations, the desirability of being able to utilize the public supply becomes more evident. In a very large number of towns and cities in England, and far more so on the Continent, in India, Egypt, and South Africa, there is a public supply of three-phase 50-period alternating current, and it appears very desirable that this should be utilized directly from the mains without any intermediate machinery.

Slide 11 gives an illustration of a transmitter which has been made to utilize such a public supply. In order to economize valves, it was decided to rectify one half-wave only and use three single rectifying valves, one between each line and the star-point of the secondary. Three oscillating valves are employed. Following the practice of stepping up to high voltage and rectification by three or six thermionic valves, or one or two three-anode mercury-vapour rectifiers, or a six-anode rectifier, with suitable storage or smoothing condensers, there is no difficulty whatever in utilizing 50-period, three-phase currents for the anode supply, but trouble arises when it is attempted to use 50-period, single-phase current for filament heating.

For some time experimentalists have been in the habit of looking upon rectification as an absolute loss, but the author would like such a suggestion to be studied, without going into the matter in too great detail here, as it seems to him that there may be advantages which outweigh the loss.

Using direct or rectified current on a valve anode which is capable of dissipating, say, $\frac{1}{2}$ kW as heat at a safe temperature, 1 kW can be applied in all to that anode, i.e. about $\frac{1}{2}$ kW to the aerial, following the safe conservative practice of working valves at an efficiency of 50 per cent. When so working, we may expect continuous waves reasonably free from troublesome harmonics; however, in order to utilize alternating current directly, whatever the frequency, at least two

valves per phase must be employed, and in addition the valves must be operated during each half-period at something like twice the rate if we are to extract as a mean value the 50 per cent for the two valves during a whole period. We are unlikely in such working to get continuous waves so free from harmonics, quite apart from the variations due to the alternations of the alternating-current power supply.

Two-phase or three-phase currents may be employed with advantage over single-phase. As is the usual practice with single-phase, each half-wave of each phase may in such case be connected to a separate anode; and a good deal of work has been done in connection with three-phase current with six valves. The author has also tested out the use of two-phase or quarter-phase currents and particularly has devised methods of producing currents of flatter wave-form than the usual sine wave-form. In this system four valves or

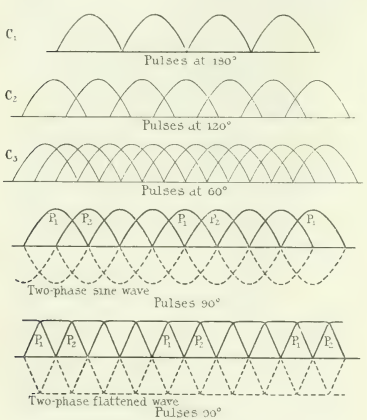


FIG. 3.—Showing the relative interference of the interrupted continuous waves produced.

a multiple of four are used. The author regrets that up to the present it has not been possible to erect test sets on the scale which is necessary to determine the relative values of the three methods, both as regards efficiency and freedom from disturbing harmonics. The rectification method would employ a six-anode mercury-vapour tube having a loss of about 5 or 6 per cent and so as to make the sets comparable, say, six 500-watt (dissipation rating) valves. The rectifier will thus be called on to give 6 kW, say 6 000 volts and 1 ampere: and since the smoothing condenser would be kept charged in pulses of 300 frequency it need be of only relatively small capacity, and with suitable filament heating arrangements very pure continuous waves would be produced.

The alternative method would consist of six valves only, and the two half-waves of each phase would be applied to an independent valve. As the valves function only when positive potential is applied to the anodes, it is obvious that each valve will operate only during half of each period. Since the valve operates on momentary values, the amount of valuable work done by each valve will vary even throughout the half-period and its useful output will be during considerably less than half the period. A six-valve set, therefore, on this system could not operate with the same size of valves if the same aerial energy is required. In practice the valves must be either 50 per cent larger

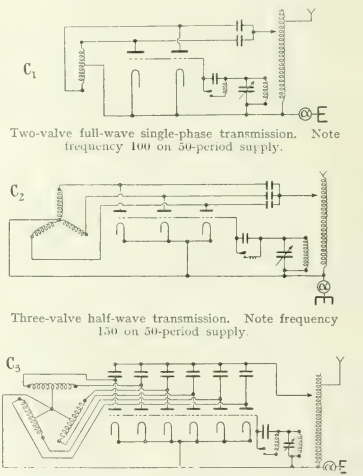


FIG. 4.

or 50 per cent more in number and the anode potential must be higher. Speaking generally, each valve will be overworked for half a period and resting through the other half, and it is probable that the harmonic troubles will be greater. In the six-valve set we have really two sets of three valves operating in parallel, each set for half of each period, but owing to the phase displacement the signal is a vast improvement on single-phase alternating-current working.

In a two-phase set, either four or eight valves must be used, or multiples of four, and there will be two or a multiple of two operating in parallel for each half-period. With sine-wave alternating currents the signal is not so good as when using three-phase currents.

For efficiency and purity of signal, there is no doubt

whatever that the honours lie with the use of direct current directly generated, and on large-scale working there is the choice of motor-generators, i.e. three-phase motors directly coupled to direct-current high-tension generators, or, alternatively, step-up transformers, mercury rectifiers and large smoothing condensers. For small sets, however, the facility with which the three-phase alternating current can be switched straight on to the valves is a tempting factor. In practice, the author believes that experience shows that 6-half-wave working is not very disturbing to local receivers, certainly not to stations situated more distant than 10 per cent of the working range of the set, and if the oscillatory current is practically free from harmonics, it is a good working proposition. Fig. 3, showing the overlapping of the phases, amply illustrates this point, and Fig. 4 shows a simple type of the circuits to be used.

Some time ago, it occurred to the author that by the utilization of two-phase currents having a flat-curve characteristic, it might be possible to produce an oscillatory current having a very small variation in amplitude. A special machine was therefore constructed in which it is possible to control the shape of the alternating current being generated, whilst the machine is running. Fig. 5 (*b*), (*c*), (*d*), shows that the top of the wave can be made practically flat for 90° and that the shape is variable, and as phase No. 2 follows phase No. 1 at 90°, practically a flat-line characteristic is produced over the

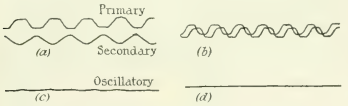


FIG. 5.

(*b*) Two-phase. (*c*) Continuous wave from flat-wave alternating current. (*d*) Continuous wave from direct current.

entire half-period. The secondary or high-tension wave is not so square-shaped as the low-tension since the transformer smooths out some of the saw-tooth ripples; it gives, however, a flat curve rather than a square wave. Owing to the facility of control of the low-tension wave-shape, it has been found possible to produce oscillatory currents of very small variation indeed, and Fig. 5 (*c*) and (*d*) gives a picture of the variations in amplitude of the continuous wave produced. It closely approaches the straight line shown by a continuous wave produced by direct current on anodes and when the method of control is applied to rotary converters it may provide, it is believed, a good substitute for direct-current high-tension generators for the medium-power field and station sets.

A transmitting set to use two-phase currents should utilize four anodes, either in the form of four valves or, for small sets, two valves having two anodes in each valve. The M.O. Valve Company's Experimental Department very kindly went to a considerable amount of trouble in producing a very satisfactory form of a two-anode valve. Samples of such valves lie on the table and may be inspected.

It is interesting to note that precisely similar aerial-current results were obtained when using two double-anode valves as when using four single-anode valves. Of course there was a reduction of filament watts, but the high-tension watts were the same in each case, although it was necessary to increase the potential for the two-anode valves, owing to the reduced anode area. Fig. 6 shows the circuit which was used for both the two-valve and the four-valve, four-anode two-phase sets. It will be observed that the extreme difference of potential across the transformers has been avoided between anodes in the same valve, and to this may be attributed the high efficiency and satisfactory working obtained. Since these experimental valves were commenced, however, the demand for ever-increasing power in continuous-wave transmitting sets has manifested itself, and the search for methods of obtaining pure continuous waves from alternating current has proceeded, using four valves for two-phase currents.

The note given by 6-half-wave sets is a pure 300-frequency note; that given by the flat-wave set with

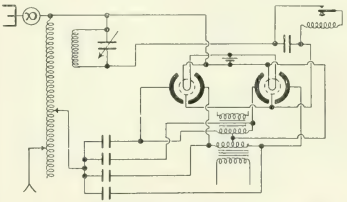


FIG. 6.—Two-phase anode circuit; continuous waves without rectification.

this special machine is, however, a musical note of possibly 200 frequency but very much smaller amplitude, for the same aerial energy radiated, than any other alternating-current working shows. By coupling a wave-meter provided with telephones to the aerial, it is possible to listen for the purest note and smallest variation of amplitude whilst varying the shape of the alternating-current wave. Whether this method may be developed into commercial practice remains to be seen, as there is a great deal of investigation work yet to be done, but there appears to be a probability of a slight gain in efficiency and possibly less harmonic interference if we can secure working with flatter alternating-current waves and exactly balance out the overlaps so as to secure uniformity of potential over all the anodes, or, in other words, average out the positive potential throughout the whole period.

The other essential to success in all continuous-wave working has been specified as "absolutely unvarying temperature of the kathode elements." The three-phase 50-period transmitting set previously described was originally designed to utilize three rectifying valves, three oscillating valves and two back-key load valves,

and it was intended to use one of the low-tension phases to supply a transformer for heating the three rectifying valves, the second phase for the back-key load valves, and the third phase for heating the oscillating valves, i.e. all single-phase at 50 periods. On conducting the trials, however, a report was received from a station approximately 400 miles away that it was not necessary to use a heterodyne as the note, although low, was very clear and distinctive. The trouble was remedied by a simple expedient due to the author, namely, that of using the three phases for filament heating, which expedient was possible owing to the fact that the three oscillating valves were operated in parallel. In this case by the use of a separate phase for heating each of the three kathodes the undesirable effect of the pulsing of the emission from the kathodes due to variations of filament temperature has been overcome.

The oscillograph shows that valves oscillated by means of high-tension direct current applied to the anodes will, if heated with single-phase current at 50 periods, send out a tonic train of 100-frequency note and, when the three kathodes were re-arranged to use the three phases, it was found that the effect was very similar to that of multiplying the frequency by three. The oscillograph also shows that the emission in such conditions pulses very slightly at a frequency of about 300 per second, but the temperature lag is too great to allow of any serious fluctuation in the total emission of the three valves at such a frequency. The actual emission of each single valve pulses with a frequency of 100, but owing to the phase relationship the total emission averages out, and very satisfactory reports have been received from near and distant stations concerning the purity of the continuous waves from the set as so arranged. As previously stated, there is no trouble in using single-phase alternating current of 200 periods and upwards.

In conclusion, it is hoped that means may be found of carrying on the research work with alternating current, but at the moment the author considers that high-tension direct current still holds the field, and for large-power sets it should certainly be possible to construct thoroughly sound direct-current generators to give 10 000 volts and, say, 20 to 30 amperes from one commutator. Such machines are, of course, quite special, and would be of the nature of special engine-driven generators or motor-generators, which arrangement would be very satisfactory, as by variation of field strength the transmitters could be more readily and safely tuned up to full power. The author has reason to believe, however, that six-phase or twelve-phase transmission could be successfully arranged, using three-phase 50-period current from public supply mains as prime mover. Twelve-phase or, rather, 12-half-wave continuous waves could be practically as pure as direct-current-generated continuous waves, but for equal harmonics it is thought that they cannot be so efficient.

The subject is so large that no apology is made for not having written for the expert, as a more general paper appeared to be needed for the average member, and to give general information to engineers and wireless enthusiasts.

The author's best thanks are due to the Chief Experimental officer of Signals Experimental Establishment and some of his staff, and the heads of departments concerned in wireless telegraphy in the War Office, and to the author's technical assistant, Mr. W. James, who is a Student of this Institution and without whose consistent help the detail work could not have been done.

Discussion before the Wireless Section, 5 April, 1922.

Mr. E. H. Shaughnessy: There are one or two minor points in the paper which interest me. The author frequently speaks of freedom from harmonics. I am not quite certain whether that is actually intended in every case, or whether he means freedom from width of band. It is rather difficult to see how the slight ripple of a direct-current machine is going to affect the freedom from harmonics, and, moreover, by using alternating-current machines with rectifiers and proper choke coils, and smoothing condensers that ripple can be reduced very considerably. On page 845 the author gives a definition of a continuous wave. He says a demand had been made for a pure continuous wave. There is no such thing as a pure continuous wave. The definition he suggests is "An undamped wave of unvarying amplitude and generally free from harmonic distortion." I should have thought that an undamped wave necessarily meant that it was of unvarying amplitude. It may be of interest, however, to those present to know that at the International Conference in Paris the question of the definition of continuous wave was considered, and it was agreed that there was no such thing as a pure continuous wave. It was thought desirable to give a practical definition, and the definition which was agreed upon was this: "Continuous waves are waves which, after reaching the steady state, are periodic; that is, successive oscillations are identical." Every continuous wave is modulated by a key or otherwise; they are modulated somehow or other, so that there are no really pure continuous waves. The author says that he does not fear any danger with large-power sets using high-tension direct-current machines. Such machines have been in use for a long time and British manufacturers who have been approached have been willing to give definite quotations for satisfactory machines of that type. The whole question, however, is one of comparative expense. It is a question of whether the cost of these machines may not be prohibitive as compared with that of alternators and rectifiers. It just depends how much is saved in maintenance, depreciation, etc., and the difference in first costs. The report of the Wireless Telegraphy Commission published last December deals with this question.

Major H. P. T. Lefroy: I think the author's summary fills what has been hitherto a distinct gap in up-to-date wireless literature, and to most of us it will be of considerable use and interest. With regard to the historical section, the author suggests that the Germans evolved, about 1916 or 1917, a certain vibrator known as the Adnil vibrator, and that, on capturing one from the Germans, we first got details of its design. As a matter of fact, this vibrator was well known to us in 1912, and

the D. Mk III Army telephone vibrator was evolved on those lines. We had an Adnil vibrator on trial at the Wireless Experimental Establishment at Aldershot, but its output was too small as then designed to be of use to us. In June 1914 a complete Adnil vibrator portable wireless set was brought over from Germany by von Lepel, and we tried it at Aldershot. It was very good in its way, but the current through the contacts was too heavy for practical work, and it was decided that it would be of no use to us until the vibrator was re-designed so as to take less current. Our intention was to use it then for aeroplane wireless sets for gun-ranging. I think I am right in saying that I heard a German using such a set from a captive balloon, in March 1915, north-east of Ypres, on 150 metres. Later I proposed to use the Adnil type of vibrator for trench-sets, and I think that during 1916 a trial model was made at the Signals Experimental Establishment, Woolwich. As regards high tension for continuous-wave generating valves, from an historical point of view it should be noted that we proposed to use such valves in the Army, in July 1914, for fortress sets, aircraft, and "wired wireless." To obtain high-tension current for these we asked the Cambridge Wireless Section, with whom we worked in close liaison at that time, to take up the design of a 600-volt, 20-watt d.c. generator, to be direct driven by a d.c. motor. Its efficiency was not considered to be of great importance, because the output was so small, but simplicity and reliability were emphasized, and also the need for minimum slot and commutator ripple. I never heard whether one was actually made or not, because the war put an end to all schemes in hand. With regard to sparks in airships, we were transmitting from airships in 1911, 1912, and 1913 with rotary spark-gaps, and luckily we had no trouble. The way we guarded ourselves then was by using the principle of the miners' lamp, i.e. by fitting gauze covers; the results were very satisfactory, as we did not have a single accident. With regard to the French instrument to which the author refers in the February, 1922, number of *Science Abstracts*, a similar machine is described; I do not know whether that is the one the author refers to, but it is also for converting direct current. Concerning the efficiency mentioned of 60 per cent for small d.c. high-tension generators, I think that some improvement might be obtained by using Yensen's iron-silicon alloys, which were reported to be extraordinarily efficient. I believe they are very expensive and hard to obtain, but the amount required would be very small, so presumably expense would not matter so much. As regards his graphs of direct-current high-tension output, would it not be an improvement if the author showed the zero line, so that we could judge the percentage ripple? On the subject of filament heating, the author has mentioned the use of alternating current up to a frequency of 200 per second. About a year ago I did some research work on the high-frequency heating of filaments, and the results were very satisfactory. I used a frequency of 100 000. Only a few dry cells were required to start the valve working, and it would then go on continuously by itself. It worked in a perfectly satisfactory manner at that frequency, and the output was sharply tuned, and supersonic, and extraordinarily steady; there was no sign of it varying in any way. I presume that it would go on until the filament failed. There was a great tendency to overheat on the part of the valve, until I learned to control it; the anode got practically white-hot at first. The high-frequency watts taken for a B2 valve for the filament were only $5\frac{1}{2}$. The current through the filament was 1·4 amperes for direct current, against 0·9 R.M.S. ampere for high-frequency current, i.e. about 50 per cent more in the former case. It seemed suitable for wireless telephony, but, as it is not possible to "key" it conveniently, it is not suitable for telegraphy. For telephony, it could be started with a few dry cells or a hand generator, and then would go on generating its own high-frequency filament current until the conversation was finished. It is not suitable for very small sets, e.g. 50 watts and under.

Mr. J. E. Taylor: I had intended to make a few remarks on the question of wave purity, but as Mr. Shaughnessy has referred to the matter I have not much to say about it, except that, in my view, we are still a very long way from anything like perfect wave purity. We can only get a really pure wave when the oscillating source is not taking up or giving out energy, but is simply sustaining an oscillation, which, of course is an impossible condition. In wireless practice, with the very best transmitters, we are very much further off that condition than is generally realized. The author has not told us much about the protective appliances, if any, which are used on the power machines. He has told us that certain types of machines have been rather liable to break down, and he thinks he has traced the cause to resonance ripples in a certain type of machine. In my view there is a much more potent source of breakdown in these machines which does not appear, for some reason, to have been fully realized. I am not going to explain at length what this source of trouble is. I may say, however, that I think I could show it to be due to an ionization effect, set up by the oscillations, occurring on the surfaces of insulators. It is well known, I think, that we get discharges which are surprisingly long compared with the maximum voltage developing at the ends of antennæ insulators, especially when continuous-wave transmitters of considerable power are concerned. That effect, I think I could show, is due to a creeping ionization along the surface of the insulator. The small initial ionization is supplemented, before it can become de-ionized, by further progressive ionization on the next oscillation, with the result that finally we have an ionized surface along the whole length of the insulator, which surface is more or less conducting and causes flash-over. The point I want to make is in connection with the protection of the generators used, because, in my view, that very effect is the one which is most potent in producing trouble in the machines. It is usually said that electric surges are the cause of breakdowns, but in my experience the term "surges" is often used to explain some effect which is not understood. I do not agree with the term in that connection at all. I think that one of the most potent causes of trouble on machines is this creeping ionization effect, which causes the discharges on insulators. Until the nature of this source of trouble is realized it is not very likely

that adequate and proper means will be taken to prevent it. I should like to hear a little more from the author as to what special precautions are taken in the design of these high-tension generators to secure immunity from breakdown, and also whether it is found that the breakdowns of machines are more frequent at the shorter wave-lengths used.

Mr. H. Faulkner: I should like to make a few remarks on some of the less important items in this paper. In the first place, on page 845 the author refers to "good signals for something of the order of 1 watt per mile, up to a limit of some hundreds of miles." I am not prepared to argue as to the signal strength that would be obtained by such powers as he mentions, but I should like to point out that the use of such an expression is unscientific, inasmuch as neither the height of the aerial nor the current in that aerial is stated. In a similar way, on the same page the author speaks of putting $1\frac{1}{2}$ kW into a 70-ft. aerial. That is certainly very misleading because there is no aerial resistance stated, and the signal strength might be anything. Further on in the paper the author gives relative figures for the lives of different types of rectifiers. He says on page 849 that the thermionic rectifier has a life of from 300 to 800 hours. These figures may be correct in reference to certain valves actually in use at the present day, but it seems to me that the effective life of thermionic valves simply depends on their design. If the filament watts be increased, and the temperature of the filament be decreased, the effective life of the thermionic rectifier can be increased considerably. The only disadvantage of a change in that direction is the increase in the filament watts. I quite understand that such an increase might be a considerable disadvantage from a service point of view, seeing that batteries, etc., have to be carried about; from the point of view of a land station, however, it is a question of economics, the increased cost being balanced against the increased life. I was going to make some remarks on the author's "safe and conservative practice" of working valves at an efficiency of 50 per cent, but in view of his statement that he preferred not to enter into any argument as to the relative advantages of working at different efficiencies I will not proceed with that. I agree with Major Lefroy that it would have been desirable if the datum lines had been given in the diagrams.

Mr. R. V. Hansford: I feel that the author has not made sufficient distinction between two possible undesirable features in valve transmitters which, to a great extent, are independent. The first is the undesirable modulation of continuous waves due to variation in the power supply and commonly known as "machine note." The second is the production of harmonics which is largely a question of the design and functioning of the high-frequency oscillatory unit of the transmitter. Now, although this paper deals principally with the question of machine note, the author frequently refers to harmonics as being the principal undesirable result, and from this point of view I think that the author's use of the word "pure" in its various forms in conjunction with continuous waves is rather unfortunate. On page 846 he uses the expression "purest possible continuous wave." On page 848 he says "nothing purer." If used at all I think the word "pure" should be restricted to considerations of wave-form, and should not be used in connection with undesirable modulations. The author does not say anything in regard to the relative advantages of the various methods of rectifying alternating current. There is a small point in connection with the use of three-phase worked bi-phase to which I should like to refer. By three-phase bi-phase I mean an arrangement of six rectifying valves relative to the secondaries of a three-phase transformer similar to the arrangement of the six oscillators in the lowest diagram of Fig. 4, such rectifiers being used in conjunction with a suitable smoothing circuit. This arrangement has a certain advantage as regards ripple. Fig. A is the usual diagram explanatory of rectification with thermionic valves, and refers to three-phase bi-phase working. The sine waves represent the voltage applied to the several anodes. Pulses of current pass through each valve in turn; they can be taken as approximately rectangular in shape, and are shown as shaded rectangles in the diagram. The voltage of the smoothing condenser will vary as indicated by the line V_0, with the consequent

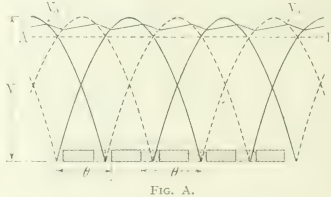
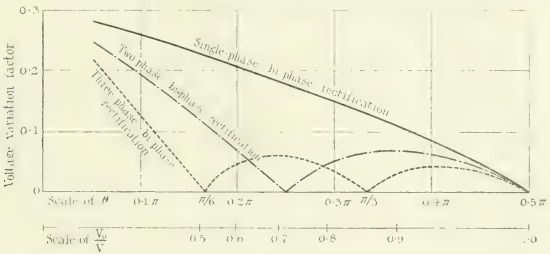


FIG. A.

ripple in the power supply. The average value of V_0 and the length of time for which the current will pass through each rectifier in turn depends on the load on the rectifier unit. If, with the unit working under the conditions indicated in this figure, the load is gradually increased, the time between the cessation of a pulse through one rectifier and the beginning of a pulse through the next will gradually decrease until a stage is reached when the rectifiers take up the load in immediate succession as indicated by the dotted lines, the voltage becomes the straight line AB without ripple, and, theoretically, a smoothing condenser is unnecessary. In practice, of course, the current-pulses are not exact rectangles, but any lags in the rise and fall of the currents are to a great extent mutually compensatory. Fig. B gives a series of curves showing the voltage variation on a single smoothing condenser for three types of rectifiers under varying conditions of load. The calculations to obtain those curves follow the lines indicated in Prof. Fortescue's paper before the Physical Society, and the symbols used are the same. The ordinates represent voltage variation on the assumption that the following factors are kept constant: the emission current of the valves used, the capacity of the smoothing condenser, and the applied voltage and frequency of the supply. The abscissæ represent θ on one scale, and its function V_0/V on another. The

amount of applied load will determine this ratio V_0/V (that is, the condenser voltage to the peak voltage); the corresponding ordinate gives the voltage variation at that particular load. The existence of definite regions of minimum ripple are clearly shown in the figure, and although the theoretical assumptions may not be strictly accurate, and it is impossible in practice to adjust the load with great accuracy, there are obvious advantages in designing the rectifying and oscillating portions of a transmitter so that the rectifiers normally function near one of these points of minimum voltage variation. The advantage of three-phase used bi-phase is that it is reasonably practicable to work near one of these points, viz. where $\theta = \pi/3$. At this point the ratio of the condenser voltage to the peak voltage is about **0·87**, and the efficiency of rectification about **90** per cent. I cannot agree with the author's conclusion "that direct current directly generated is inherently the best form of power." It seems to me that if a three-phase I should just like to emphasize what Mr. Shaughnessy said about the economic side of this question which has been largely ignored in the paper. In view of the fact that high-tension direct-current machines are quite a commercial proposition nowadays, it would be interesting if the author could give us data of the relative costs of operating valve transmitters with d.c. and a.c. supply.

Professor G. W. O. Howe: I was rather impressed by the fact mentioned by the author that the sparkless operation of one of the machines was regarded as essential for its use in aircraft. Such a statement rather suggests that people were depending for safety on the sparklessness of this machine. I do not think that, personally, I should care to rely for absence of explosion on the sparklessness of any dynamo, even if it were guaranteed by all the scientific people in the world. I presume that, in addition to trusting to its sparklessness, the machine was properly enclosed somewhat on the same lines as a safety lamp. As the author



Comparison of voltage variation with single-, two- and three-phase rectification (using two rectifiers per phase in bi-phase in each case. Voltage variation (σ) = Ordinate = $\frac{f_0 - f}{f}$

FIG. B

public power supply is available there is a good deal to be said in favour of the use of thermionic rectifiers.

Major B. Binyon: There is one thing that I wish to mention, and which I think comes within the scope of the paper, although it has not been touched upon by the author or by previous speakers, and that is the provision of power for wireless receivers. I should like to ask the author whether he knows of any work that is being done on the production of a telephonically silent small-power generator suitable for use with receiving valves. The author mentioned the popularization of wireless receiving apparatus in his supplementary remarks, and in this connection it would be interesting to know if it is possible to produce a machine which will compete with the dry cell and small accumulator, both from the points of view of being telephonically silent and of durability. In connection with the author's supplementary remarks about high-tension machines, I do not think he is very up-to-date, because in **1910** I was working with a machine commercially bought, not specially built, which gave 5 000 volts at 2 amperes, and was certainly a very practical and reliable machine. rightly said, this is a very wide subject, and he has been able to touch on many things in only a very superficial manner. In several cases his superficial remarks only whet the appetite for more information. This paper certainly brings home to us the enormous amount of research work that has been put into the design of the small high-voltage machines. Anyone who is familiar with dynamo design and who takes the trouble to calculate out the voltage per segment in the commutators of these machines, will find that values are used which the ordinary commutator designer would consider quite impossible. We are told on page 847 that Slides 6 and 7 show a 1-kW rotary transformer. We are told the diameter of the commutator of that transformer, but we are not told the number of segments. Also, referring to page 848, I should be pleased if the author could tell us the speed of the machine mentioned there. [**Major Swinton:** 2 500 r.p.m.] I also noted that in all the oscillograms the base line is missing. The wavy line showing ripple may mean a very big ripple or a very little ripple, according to where the base line is. It would also be interesting to know whether

the machines were on load or not in every case. I believe it is stated in one case but not in another. I should like to know whether these machines were on load when these ripples were taken, because in many of these machines armature reaction plays an important part and may disturb the shape of the field and modify the ripple. When dealing with wave-forms and, especially, with these square-topped waves, it is very important to know whether the machine is on load and subject to armature reaction or not. I was very much interested in the reference the author makes to a special machine which had been constructed in which it is possible to control the shape of the alternating current generated while the machine is running. That is a point about which one cannot help feeling very curious, and I should like more information about it. From what the author said, I presume it was merely done by altering the field strength. In connection with a remark by Mr. Taylor, I may say that I am a believer in surges. I do not think that the term is always used as a cloak for ignorance although it is convenient to use it in that way; chemists have a term which they employ in the same manner, when they do not understand what happens they call it catalytic action. As a matter of fact, however, it may be remembered that about a year ago there were two very interesting papers

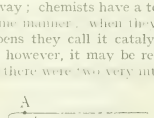


FIG. C.

in the *Archiv für Elektrotechnik*. A high-voltage dynamo had broken down, and another that was sent to replace it also broke down immediately, and two independent papers, one by K. W. Wagner and another by Rogowski, were written, one proving that the trouble was due to surges, and the other proving that it was not due to surges, but to resonance effect. Let AB (see Fig. C) represent the armature winding of a direct-current dynamo, the terminal B being earthed and therefore at zero potential and the terminal A at 10 000 volts. Assuming for the sake of simplicity that the total voltage is equally divided between 10 sections of the winding, the voltage across AC will be 1 000. If, now, the wire connected to A sparks to earth or to the other lead, a surge travels along the wire to A, and suddenly reduces the potential of A to zero. Owing to the distributed inductance and capacity of the winding AC some time elapses before the potential of C is affected, hence for a moment there is a very large potential difference between A and C, in our simple example 9 000 volts. It is to guard against such surges that the end turns of transformers and motors are often specially insulated.

Dr. N. W. McLachlan (*communicated*): Although the paper deals specifically with the supply of power for small units, it raises in a measure the issue between the use of rectified alternating current and that of direct current from d.c. generators for anode feed purposes in large and small sets. With large-power units, say 100 kW, the scheme adopted will depend to a great extent on the conditions associated with the transmitting station. Neglecting, for the moment, any slight irregularities which may occur in the transmitted wave due to imperfect smoothing after rectification, if a cheap, well-balanced three-phase supply is available, and it is desired to reduce capital cost to a minimum, the decision will generally be in favour of rectification. Whichever alternative is adopted, it will be necessary in general to install transformers in order to get a suitable working voltage. Where no convenient supply is to hand it will be preferable to employ a d.c. generator or several such units in series. Examples of the use of d.c. generators will be found at Clifden and Glace Bay, where the units, manufactured by Dick, Kerr & Co., and installed about the year 1906, are of 5 000 volts each, the commutator bars being air-insulated. These machines were used, until the recent replacement by valves, for working in conjunction with the old spark sets. At Carnarvon the experimental valve set, used recently to transmit to Australia, was fed from four d.c. machines in series. A three-phase supply is to hand at this station, but it so happened that the generators were installed some years ago to run the timed-spark apparatus, and it was, therefore, unnecessary to have recourse to rectification. The problem of using a three-phase commercial supply has not yet been treated on an extensive scale, but there ought not to be any great difficulty in adapting a supply of this nature to rectification and filament lighting. Using the author's adaptation of three-phase current to filament lighting, it appears that unless dummy resistances are used the number of valves must be a multiple of three; and at times this might prove inconvenient. I should think that a simpler way of coping with the matter would be to use the Scott method of converting three-phase current to single-phase, but I should like the author's opinion on the subject. The question of overall power factor is one which merits attention; perhaps the author can give some figures relating to his own sets. I should be glad if he would state where the transmission key is usually situated, and if any trouble has been encountered due to transients during keying, with either rectifiers or d.c. generators. The effect of transients is, of course, likely to be more marked with large sets dealing with heavy currents. With small stations, say 6 kW, the matter regarding anode feed assumes a slightly different aspect from that stated heretofore. Many small sets have been designed and partially standardized, single-phase rectification being used almost universally, although three-phase has been tried with beneficial results. The supply is generally generated in situ using an internal-combustion engine or a motor to drive the generator, the frequency being 300 if single-phase. In this case I believe that rectifiers are cheaper than a d.c. generator. The author refers to constancy of filament temperature and therefore to unvarying electron emission (for any given voltage on the valve). In this respect I should be glad to know how he provides for fluctuations in voltage across the primaries of the filament-heating transformers, assuming the supply to be single-phase or three-phase.

Major R. C. Trench (*communicated*): The author has sketched a process of evolution from which direct current generated at high tension emerges as the fittest survivor to-day; he shows us as a possible competitor two-phase or multi-phase alternating current transformed up to the voltage required. From the point of view of small portable continuous-wave sets, which must carry with them their own source of power, it does not look as if the direct-current high-tension generator has at present any serious competitor. These machines are becoming very reliable; they possess great freedom from ripple and have the advantage, for work in the field, of producing a high voltage in one operation without the medium of a transformer, the use of which means an extra instrument to carry about. There is, however, an important point in which the multiphase method can claim an advantage, namely, that it avoids the difficulty of having to produce under field conditions such high speeds as 5 000 r.p.m. If it can be made reasonably free from ripple, this advantage may yet bring it to the front for such small stations. In addition, the feeling that a low-voltage generator with static transformer is more robust for field conditions than a high-voltage generator is probably still well-founded in spite of all improvements in the latter instrument. For larger stationary sets where the local supply is three-phase 50-period alternating current, the advantage of being able to obtain high tension for the valves simply from a transformer connected to the mains must be great, and it seems that this method may have a future on this account alone, in spite of the inevitable persistence of a certain amount of ripple. A public supply would not have the advantage for wireless purposes of a flat-top wave. On this point, however, I speak as a layman with little experience of work under these conditions. The author's paper implies that continuous waves produced in short trains at audible frequency have dropped out of the race owing to the interference which they cause. It appears, however, that such a method might permit of acoustic tuning at the receiving end, and so confer on stations in its own system an additional selectivity at the expense of its neighbours. It would be interesting to know if the author's experience has led him to form any opinion on this aspect of the question.

Major J. H. Whittaker-Swinton (*in reply*): I very greatly appreciate the comments and criticisms of the meeting and consider that each speaker emphasized the vastness of the problem. The paper was drafted in such a way as to call for free discussion, which I hoped would bring out much that would be helpful to members.

Mr. Shaughnessy and Mr. R. V. Hansford dwell on the question of purity of "undamped waves," and the illustrations of the voltage variation at the smoothing condenser shown by the latter were most interesting. My point, however, is that the direct current or unidirectional supply to the anodes should be absolutely unvarying if an undamped wave of unvarying amplitude is required. If, then, the other two conditions set out or implied in (*b*) and (*c*) at the foot of page 845, namely, absolutely unvarying filament temperature in the oscillating valves, and the best-known conditions are fulfilled in the design of the oscillatory circuit and aerial, continuous waves more than satisfying the Paris Conference definition will be forthcoming. I have a feeling that the Paris definition of continuous waves is somewhat of a compromise, but, even so, a source of power having a ripple or variation of voltage due to intermittent rectification and inadequate smoothing condensers, will fail to satisfy the condition that each successive wave shall be identical with the first "steady" wave. It must be noted, however, that "wireless" waves produced by means of alternating current without rectification are not "continuous waves," according to the Paris definition, and in all rectification systems any periodic variation of the voltage (P.D.) of the smoothing condensers following the peaks of the alternating current being rectified, will prevent the fulfilment of the condition that "Successive waves shall be identical with the first steady wave." It is not that each successive train shall be identical but each oscillatory wave, and the smoothing condensers or choke scheme in the rectification system must vary with the frequency of the a.c. power plant, and with 50-period alternating current needs to be of considerable capacity, or 6-half-wave or 12-half-wave rectification must be resorted to. There is, however, a serious possible oversight in the Paris definition in that the first stable and the successive identical waves may be so distorted with harmonics as to be a veritable harmonious band of waves, and yet they will comply with the demands of the International Conference, because the *first steady* wave was "full of harmonics." We should seek to secure (1) a pure form of wave in the fully built-up steady wave; (2) that each successive wave shall be identical in amplitude, i.e. there must be no periodic variation in amplitude, and we shall then have continuous waves in accordance with my definition. Mr. Shaughnessy remarks that an undamped wave must necessarily be of unvarying amplitude, but that surely excludes most forms of interrupted continuous waves or tonic train, or wireless waves produced by means of alternating current without rectification. I rather fancy that the words "undamped waves" are being loosely used as generally including all waves which are not damped in the manner of spark wireless systems. Wireless waves which vary in amplitude in accordance with the varying potential difference of the a.c. power employed are surely modulated, undamped, oscillatory waves, i.e. not damped in the generally accepted sense but modulated in amplitude at the power frequency. A commutator ripple gives rise to a similar form of modulated undamped wave, which can be received without heterodyning, and an inadequately smoothed rectification system may easily be similarly bad. A varying temperature in the filaments of oscillating valves, where the variation is periodic, produces similar results, as instanced on page 852 of the paper, but according to the Paris definition and its general acceptance, no one is likely to say that the waves were not "continuous," or that they were "damped waves," although each successive wave varied in amplitude, i.e. modulated at the periodicity of the current used to heat the filaments. The subject was too big for one paper and I chose, therefore, to deal chiefly with the

necessity of a rippleless source of power and absolutely unvarying temperature of filaments, but freedom from harmonic distortions of wave-form is of paramount importance.

The wave-shape of the "steady oscillations" may be such that the ether is filled with music. A message nominally on one wave may obliterate many others, and the listeners-in on all wave-lengths for miles around will suffer in consequence. Thanks are due to Mr. Hansford for bringing out this point as regards impurities due to bad wave-form as well as undesirable modulations. The machinery used controls the latter in the main, and the wireless designers should look after the former, having secured a satisfactory source of power. What Mr. Hansford calls "three-phase bi-phase" I have called "six half-wave," and I agree that six thermionic rectifiers might possibly be adjusted in a laboratory so as to ensure equal emission at the six half-waves so as to work with a small smoothing system (or none at all), but in practice such adjustments are not possible as they involve the provision of suitable and accurate meters in each lead to the condensers, etc. The length of dots and dashes, and the variation of sequence might also have to be considered before agreeing that "theoretically, a smoothing condenser is unnecessary." There is also the matter of identical impedance of the rectifying valves used on the six half-waves, which in practice works out well enough by the simple expedient of a relatively large smoothing system, but the machine giving direct current directly generated is free of these faults, and there are six things less to worry about in the endeavour to carry on wireless traffic with the minimum of interference with others.

I agree with Mr. Faulkner that it would be more scientific to give all the factors in a transmitting system if I were attempting to prove that reliable communication could be maintained for the expenditure of 1 watt of energy per 1-mile range. I referred, however, only to the relatively small power required by continuous waves, for the purpose of emphasizing the usefulness of the very small rotary transformers shown at the meeting. The case of $1\frac{1}{2}$ kW put into a 70-ft. aerial may, however, be completed, the aerial resistance being 8 ohms and the strength of signal R7, but the latter may mean anything and is a very unscientific term, as at present there is no standard of signal strength.

It is quite true that the life of all thermionic valves depends on the temperature of the filaments, and the average life which I quoted is obtained from valves in which the filament watts amount to approximately 10 per cent of the energy passed through the valves. For large stations I consider the mercury rectifier to be a better proposition, and I suggest the use of 6 or 12 half-waves with 6 or 12 anodes in one tube, which would allow 50-period, three-phase public supply to be utilized without the use of any machinery. I am unable to give, at the moment, data of the relative costs of operating valve transmitters from d.c. or a.c. supply, but I hope to be in a position to do so as soon as the capital costs of d.c. high-tension machinery are ready for publication by the firm with which I am now associated. Possibly Dr. McLachlan's conclusion will be found to be sound, viz. "where a cheap, well-balanced three-phase supply is available, and it is desired to reduce capital cost to a minimum, the decision will generally be in favour of rectification," but if the station must run on economic lines, i.e. pay as a commercial concern, the two factors (*a*) and (*b*) must be considered together, and then (*c*).

(*a*) Capital cost of step-up split-phase transformers, plus rectifying valves and panels, smoothing condensers and chokes and continual replacements, as against
(*b*) Capital cost of motor-generators.
(*c*) The relative efficiency of conversion to high-tension direct current at the anodes of the transmitting valves.

When the balance is taken there may not be much in favour of either method, except ease of working, but for a station where the power has to be generated I think that d.c. generation would be decided upon. I feel that the use of 50-period single-phase current is not possible, and the Scott method or any other transformer method of phase-changing cannot alter the periodicity except with considerable expense and complications as to wave-form, etc., hence I do not follow Dr. McLachlan's suggestion of conversion of three-phase to single-phase current as a simpler method of coping with the difficulty of pulsation of emission due to variation of temperature at a low frequency.

If the transmitting valves cannot be fairly equally divided and heated by all three phases, there are two other alternatives. The first is to provide three-phase filaments to each valve, i.e. three limbs instead of the usual two as in the hairpin filament, or, better still, three hairpin filaments so connected as to tap the star point for the oscillatory circuit, by which means all the limbs of the filaments are subjected to similar conditions as to temperature and emission, and the life of all valves will be increased (see Fig. D). An incidental advantage in this method of filament construction lies in the improbability of all three limbs failing together, and the immediate traffic could be finished before replacement. The other alternative is to run a motor-generator and supply direct or alternating current at higher frequency to the filaments.

Alternating current is more convenient for filament heating than direct current, because of the ease with which separate sources can be provided for valves between which there is a considerable potential difference, e.g. in series valve working and where series valves are used as control valves. With the three-phase filaments 50-period current can be very successfully used for control and all other purposes. The heating transformers can also be compounded to compensate for the drop in the supply pressure under key load. The question of provision against fluctuations in the supply pressure due to causes outside the transmitting station is another matter, and in practice is hardly likely to arise in the case of public supply, but where a.c. generators have been driven by petrol engines I have designed a trip switch to operate in the exciter circuit in case of a serious rise in the filament voltage.

Mr. Taylor raises the question of protective devices. I prefer to avoid, as far as possible, placing reliance on

these. It has been common practice to connect a large smoothing condenser across the armature of a high-tension d.c. machine to smooth out the ripples, but it is better to insist on absence of ripple. The value of such a condenser, which frequently affected the design of the transmitter circuit, was determined solely by the necessity of removing so-called commutator ripple which was generally slot ripple.

The ratios C/L of the machine and of the smoothing condenser, to the slot frequency have seldom been considered, hence a condition arose where machines burnt out successively at a critical speed, and it was the fact of such burn-outs occurring when the high-tension system was cut off from the oscillating circuit which led to alterations in the design of the machinery after investigation of the conditions. In this connection I think I may say that the Services have found no difference as regards burn-out of d.c. machines when transmitting at various wave-lengths. Trip relays are fitted in the negative high-tension lead to the oscillating valves to operate in the case of abnormal anode current passing, e.g. surges or any instability in the valves, or where a valve or valves "blue," and these have proved to be invaluable protectors in such cases and in case of

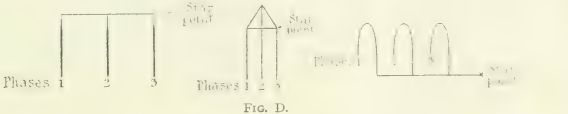


FIG. D.

mistuning. As to ionization causing discharges on insulators, I find that this generally takes place outside the machine itself, and where such flashes have occurred, e.g. at condensers, etc., the relays have acted with promptitude and success. The system of insulation in the high-tension armatures is such that the commutator is the only part carrying high-tension current which is exposed to the atmosphere, and I have not had a case of flash-over, although many machines have now been handled.

In spite of Professor Howe's remarks concerning the sparklessness of high-tension machines for use in aircraft, he would no doubt appreciate such operation, particularly if he had to persuade pilots to go aloft and operate the extra apparatus. Sparkless commutation and absence of ripple are essential requirements in a good machine, and the number of commutator bars should be very high. My statement that the oscillograms were relative to each other appears to have been overlooked. The difference in the ripples in the case of the motor-generator with few, large, wide, straight slots and the rotary transformer with many narrow, skewed slots is very marked. In the one case a smoothing condenser of comparatively large value (say $0{\cdot}5\ \mu$F) is imperative although a source of danger, and even then the so-called commutator ripple can be picked up with a wireless receiver without heterodyning for many miles from the aerial, whilst the rotary transformer does not require a condenser and no note is discernible.

I regret my inability to give a base line, but a little consideration will show how difficult that operation would be with an oscillograph at a d.c. pressure of 3 500 volts or higher. The tests were taken on load. Dr. Howe's diagram and explanation are useful in explaining the burn-outs due to ripple resonance, and my experience is that such surges undoubtedly take place at a critical speed.

In reply to Major Binyon I may say that Messrs. Newtons of Derby have produced a very light rotary transformer specially for receivers, and I believe that it will compete with dry cells in the long run. Its construction is such that smoothing chokes are not required. I should be surprised if the machines referred to as giving 5 000 volts and 2 amperes in 1910 were British made and commercially bought in the generally accepted sense. During the war our wireless engineers lamented sorely the absence of any form of high-tension d.c. machine, particularly small machines.

Major Trench's appreciation of small machines for field use is very gratifying, and he will be glad to hear of the production of high-tension generators at speeds approximating to 1 500 r.p.m., which can easily be driven by a small petrol engine and render the wireless telegraph section independent of batteries. I agree with him as to the use of note trains in small sets and have suggested an a.c. machine for the purpose of small forward trench wireless sets, capable of giving at will alternating current at any one of six frequencies, so as to enable at least six sets to operate in a crowded area on the same wave-length. Such sets would be tonic-train sets and heterodyne would not be used in the reception.

Lastly, I thank Major Lefroy for his remarks, for correcting historical matter, and for additional facts. His data concerning valve filament heating by high-frequency current are very interesting and the method is very fascinating in the laboratory. In practice one must remember, however, that all the high-frequency energy comes from the high-tension d.c. anode supply and is not efficiently produced. The $5\frac{1}{2}$ watts taken from the oscillatory circuit to heat a B2 valve might easily have been consuming 10 or 12 watts of high-tension energy which had been especially transformed or generated for anode supply.

My supplementary remarks concerning Continental practice have been referred to by Major Binyon and I think it is well to repeat the technical portion here.

In Germany it is common practice to employ a motor-alternator. The periodicity is usually high, say 250 or over. Each transmitter is fitted with a rectifying

valve or, generally, duplicate valves. The Post Office 500-watt and 1 kW sets use mean single-phase, two-anode receiving valves, whilst the P.O. 6 kW and 12 kW transmitters use single-phase two-anode, mercury-vapour rectifiers. The electromotive force is about 3,500 volts (line to star) in all cases, and a little higher in the larger sets, but the d.c. voltage under load is about 3,000/3,500. I do not think they have yet used polyphase currents. For single transmitters or small stations a separate motor-alternator is used for each transmitter, and the filaments are heated by low-tension alternating current supplied from a special transformer, as their filaments are usually *above* earth potential owing to the circuit employed in the transmitters. In larger stations for concentrated working there is a central source of high-tension single-phase current to which a number of the smaller transmitters are connected. I have seen ten or twelve 500-watt and 1-kW sets so connected in one room; each transmitter was, of course, connected to its own aerial overhead. As these transmitters were "remote controlled," i.e. operated by the girl operators in the Post Office building some 20 to 30 km away, exactly as ordinary line telegraphs, it was necessary to maintain the transmitters in a condition of "ready to oscillate," and they are, as a matter of fact, so arranged as to consume about half current or half load when "key is up." They thus consume 50 per cent more energy with key down but take half load current all the time. The rectifiers and the valves are continuously at work.

With large sets it is desirable to arrange for a back-key load, and in all cases it is preferable to contrive that the act of keying does not produce violent swings or changes of potential, but I look forward to a more efficient arrangement in which the valves will not be so harshly treated.

If British engineers should find it necessary to work wireless as an exchange is worked (as is being done in Germany, i.e., say, a central station in London with aerials for Harwich, Queensferry, Ramsgate, Dover, Folkestone, Newhaven, Southampton, Plymouth, Exeter, Bristol, Newport, Cardiff, Holyhead, Gloucester, Birmingham, Liverpool, Glasgow, Hull, etc., I think that a large d.c. generator would be a better proposition and save the use of rectifiers altogether. Back-loading would then not be necessary.

The problem in the concentrated stations on the Continent includes the production of "pure continuous waves," and a great deal is sacrificed to ensure "freedom from harmonics." It is for this reason that their rectifiers are kept going and the valves half back-loaded, and their success is undeniable. The speed of working is about 700 letters per minute.

In the concentrated stations I noted that all the transmitters were fitted with "intermediate" or "closed" circuits, i.e. they were coupled to the aerial more or less loosely, and less energy at harmonic frequencies is passed to the aerial system. I gathered, indeed, that concentrated transmission is impossible with the direct method of working as used in the Army.

THE PROPERTIES OF THE DISTRIBUTION FACTOR OF ARMATURE WINDINGS.*

By B. HAGUE, M.Sc., and S. NEVILLE, B.Sc., Associate Members.

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SUMMARY.

In many problems the resultant of a number of equal and equally spaced vectors is required in terms of their simple scalar sum. This relation is usually expressed in the form of a ratio

$$f(\theta) = \sin \theta/q \sin (\theta/q),$$

where q is the number of vectors spaced over an angle 2θ.

The vectors may be those of the electromotive or the magnetomotive force of the coils of an armature winding; the quantity $f(\theta)$ is then called the *distribution factor*, and is of frequent occurrence in the theory and design of armature windings.

The object of this paper is to discuss the principal mathematical properties of the distribution factor, and to give a complete series of curves exhibiting these properties in a form suitable for practical application.

In many physical and engineering problems it is necessary to add together a number of equal and equally spaced vectors, or other quantities which may be similarly treated. It is obvious from symmetry that the resultant lies midway between the extreme components; that is, it coincides in direction with the middle vector when there is an odd number, or with the bisector of the middle angle when there is an even number of vectors. It is required to express its magnitude as a fraction—positive or negative—of the resultant which the vectors would yield if they were all concentrated at the middle position and therefore directly additive.

In electrical engineering a very important instance of this relationship is found in the calculation of the electromotive or magnetomotive force of an armature winding. In this connection the ratio in question is termed the *distribution factor*, since it represents the fraction to which the E.M.F. or M.M.F. is reduced, on account of the conductors which constitute the winding being distributed over a definite arc of the armature periphery, instead of being concentrated in a single slot situated at the middle of the group.

The mathematical form and many of the properties of this factor have been given in various places,† and it is the object of this paper to summarize such information for convenient reference, and to illustrate the variations of the function by a complete set of curves from which numerical values may be taken for practical purposes.

The expression for the distribution factor is very easily deduced either analytically * or from the following simple geometrical construction. Let q denote the number of component vectors represented as intersecting at a point O, Fig. 1 (*a*),† and let θ/q be one-half of their angular separation; that is to say, a total angle 2θ

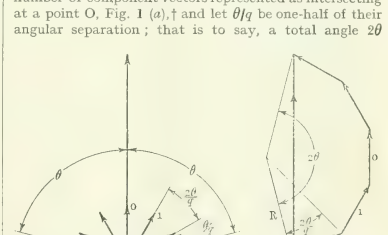

FIG. 1.—(*a*) Arrangement of vectors; (*b*) Vector polygon.

is divided into q equal parts and a vector acts at the middle point of each part. Then, in the corresponding vector polygon, Fig. 1 (*b*),† it is seen that the resultant

* Let the component vectors be of positive unit length with an angular spacing of $2\theta/q$ between them. Resolving into components along and at right angles to the middle vector (assuming an odd number of vectors), the two components of the nth vector, counted from the middle one as zero, are respectively $\cos(2n\theta/q)$ and $\sin(2n/q)$; so that the corresponding components of the resultant are

$$X = \sum_{-(q-1)/2}^{+(q-1)/2} \cos 2n\frac{\theta}{q} = 1 + 2\sum_{1}^{(q-1)/2} \cos 2n\frac{\theta}{q}; \qquad Y = \sum_{-(q-1)/2}^{+(q-1)/2} \sin 2n\frac{\theta}{q} = 0$$

Hence the resultant coincides in direction with the middle vector and has the magnitude X. Now

$$X \sin \frac{\theta}{q} = \sin \frac{\theta}{q} + 2\sum_{1}^{(q-1)/2} \sin \frac{\theta}{q} \cdot \cos 2n\frac{\theta}{q}$$
$$= \sin \frac{\theta}{q} + \sum_{1}^{(q-1)/2} \left[\sin (2n+1)\frac{\theta}{q} - \sin (2n-1)\frac{\theta}{q}\right]$$

Inserting successive values of n, alternate terms cancel, leaving $X \sin (\theta/q) = \sin \theta$. The resultant of the vectors when concentrated at the position of the middle vector is clearly q; therefore $f(\theta) = X/q = (\sin \theta)/q \sin (\theta/q)$. A precisely similar argument applies when q is even, and leads to the same result.

† Figs. 1 (*a*) and 1 (*b*) should be compared with similar diagrams given by S. P. SMITH and R. S. H. BOULDING: "The Shape of the Pressure Wave in Electrical Machinery," *loc. cit.*, Fig. 23; and S. P. SMITH: "The Theory of Armature Windings," *ibid.*, 1917, vol. 55, p. 19, Fig. 1.

* The Papers Committee invite written communications (with a view to publication in the *Journal* if approved by the Committee) on papers published in the *Journal* without being read at a meeting. Communications should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† E. ARNOLD: "Die Wechselstromtechnik," vol. 3, p. 200. S. P. SMITH and R. S. H. BOULDING: "The Shape of the Pressure Wave in Electrical Machinery," *Journal I.E.E.*, 1915, vol. 53, p. 205 (quoted with further discussion by Prof. MILES WALKER: "The Specification and Design of Dynamo-Electric Machinery," pp. 32 and 305). B. HAGUE: "Pressure Harmonics in Polyphase Systems and Windings," *Electrician*, 1917, vol. 78, pp. 710, 740, and 765. C. A. ADAMS: "Electromotive Force Wave-shape in Alternators," *Transactions of the American Institute of Electrical Engineers*, 1910, vol. 28, pt. 2, p. 1053.

is $2R \sin \theta$, and that its direction corresponds to that of the middle vector (or the bisector of the middle angle) in Fig. 1 (*a*). Each of the components is $2R \sin (\theta/q)$, so that their resultant when directly superposed is $2qR \sin (\theta/q)$. Hence the ratio of the sum of the q vectors when distributed, to their resultant when superposed, is

$$f(\theta) = \frac{\sin \theta}{q \sin (\theta/q)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

This ratio * will be considered as a function of θ as a continuous variable, with q as a positive integral parameter.† For the smaller values of q the function is of a very simple form, as may be demonstrated by the following transformation:

$$\begin{aligned}\sin \theta &= \sin q(\theta/q) \\ &= {}_qC_1 \sin (\theta/q) \cos^{q-1}(\theta/q) - {}_qC_3 \sin^3 (\theta/q) \cos^{q-3}(\theta/q) \\ &\quad + \ldots (-1)^{\frac{n-1}{2}} {}_qC_n \sin^n (\theta/q) \cos^{q-n} (\theta/q) \ldots\end{aligned}$$

where ${}_qC_n = q(q-1)(q-2) \ldots (q-n+1)/n!$ is the binomial coefficient of order q.‡ The series terminates when $q = 3$, $f(\theta) = \cos^2 (\theta/3) - \frac{1}{3} \sin^2 (\theta/3)$

$$= \tfrac{1}{3} + \tfrac{2}{3} \cos (2\theta/3) \quad . \quad . \quad . \quad (4)$$

and when $q = 4$, $f(\theta) = \cos^3 (\theta/4) - \cos (\theta/4) \sin^2 (\theta/4)$

$$\begin{aligned}&= \cos (\theta/2) \cos (\theta/4) \\ &= \tfrac{1}{2} \cos (3\theta/4) + \cos (\theta/4) \quad . \quad (5)\end{aligned}$$

Thus, when $q = 2$, the variation of $f(\theta)$ is a simple cosine curve; when $q = 3$, $f(\theta)$ is again a simple cosine curve about an axis at $f(\theta) = +\ 1/3$, or alternate large and small oscillations about the axis of θ; when $q = 4$, the function can be expressed as the sum of two cosine curves of different wave-lengths. With more than four components the variation is not so simple, and the results of the above transformation are of little interest.

It will be obvious that $f(\theta)$ is a periodic function of θ, and that the general shape of the curves has its origin in the simultaneous harmonic variations of the numerator and the denominator of expression (1) at different rates. The numerator alone would give a uniform sinusoidal variation with an amplitude $1/q$, the curve representing it passing through zero at the origin and wherever θ is an integral multiple of π. The effect of

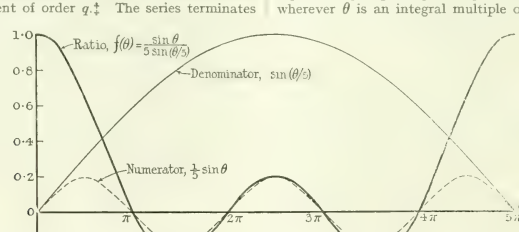

FIG. 2.—Derivation of distribution factor for $q = 5$.

at the term containing ${}_qC_q$ when q is odd, or ${}_qC_{q-1}$ when q is even, since ${}_qC_{q+1} = {}_qC_{q+2}$, etc., are zero, and n is an odd integer. Hence

$$\begin{aligned}f(\theta) &= \frac{\sin \theta}{q \sin (\theta/q)} \\ &= \left[\cos^{q-1}(\theta/q) - \frac{(q-1)(q-2)}{3!} \sin^2 (\theta/q) \cos^{q-3}(\theta/q) \right. \\ &\quad \left. \ldots \frac{(-1)^{\frac{1}{2}(n-1)}}{q} {}_qC_n \sin^{n-1}(\theta/q) \cos^{q-n} (\theta/q) \right] \\ &= \sum_{n=1,3,5\ldots}^{p} \frac{(-1)^{\frac{1}{2}n-1}}{q} {}_qC_n \sin^{n-1} (\theta/q) \cos^{q-n} (\theta/q) \quad . \quad (2)\end{aligned}$$

where the upper limit, p, is q when q is odd, and $q - 1$ when q is even. Applying this series we obtain,

when $q = 2$, $f(\theta) = \cos (\theta/2)$ . . . . . (3)

the denominator is to increase the ordinates of this curve in a continuously varying ratio; so that, while the oscillatory form remains, the variation of $f(\theta)$ is not generally sinusoidal. To illustrate this, the numerator, denominator, and their ratio, are plotted separately in Fig. 2, for the particular case when $q = 5$.

From expression (2) it is clear that $f(\theta) = 1$ when $\theta = 0$, whatever be the value of q. As θ increases from zero, $f(\theta)$ continually diminishes until it becomes zero when $\theta = \pi$; i.e. when the q vectors are uniformly spaced over a complete circle. The function then changes sign, passes through a negative maximum and declines again to zero. Thereafter it passes through zero whenever θ is an integral multiple of π, except in the cases when $\theta = kq\pi$, where k is any integer. In these instances $f(\theta)$ becomes $\sin k\pi / q \sin k\pi = (-1)^{k(q-1)}$. Thus, whenever θ is an integral multiple of $q\pi$, i.e. when the q vectors are coincident, the curve rises to a value of unity, positive or negative according to the values of k and q. When q is odd all the unity or principal maxima are positive; but when q is even they are alternately positive and negative. Between two zero values, the one following a principal maximum and

* The late Prof. S. P. Thompson proposed to call the function $f(\theta)$ "persine θ" (see *Journal I.E.E.*, 1915, vol. 53, p. 240).

† See footnote on page 865.

‡ HOBSON: "Plane Trigonometry," 3rd edn., pp. 52 and 272. For a detailed discussion of the expansion, see G. CHRYSTAL: "Algebra," pt. II, 2nd edn., chaps. xxvii and xxix.

the other preceding the next principal maximum, there are $(q-2)$ subsidiary maxima of small amplitude—never exceeding 0·333. Further, at the points where θ is an odd multiple of $\pi/2$ the numerator has maximum values of $\pm 1/[q \sin (1, 3, 5 \ldots)\pi/2q]$, indicating that the smaller oscillations diminish in amplitude to a point midway between two large oscillations, after which they increase again. At this middle point (or $\theta = q\pi/2$) the function is zero if q is even, and $\pm 1/q$ if q is odd.

The true maxima of $f(\theta)$ occur, however, at points defined by

$$\sin\theta \cdot \frac{d}{d\theta}[\sin(\theta/q)] = \sin(\theta/q) \cdot \frac{d}{d\theta}[\sin\theta]$$

that is, by $$\tan(\theta/q) = (\tan\theta)/q \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The solutions $\theta = kq\pi$ give the series of unity maxima already described, while the intermediate roots define the positions of the $(q-2)$ series of subsidiary maxima. For example, in the case when $q = 5$, the roots of the equation

$$\tan(\theta/5) = \tfrac{1}{5}\tan\theta$$

are approximately $\theta = 0,\ 1{\cdot}45\pi,\ 2{\cdot}5\pi,\ 3{\cdot}55\pi,\ 5\pi,\ 6{\cdot}45\pi$, etc.; and from (1) the values of $f(\theta)$ at these points are approximately $+1{\cdot}0,\ -0{\cdot}25,\ +0{\cdot}2,\ -0{\cdot}25,\ +1{\cdot}0,\ -0{\cdot}25$, etc., as seen in Fig. 2.

Since, numerically, $f(\theta)$ is periodic with range $q\pi$, and is symmetrical about its maximum values, it is convenient in practical work to replace θ by a new variable α, which is the amount by which θ exceeds or falls short of one of its values which yields a positive or negative maximum of $f(\theta)$; that is, $\theta = kq\pi \pm \alpha$.

Then

$$f(kq\pi \pm \alpha) = \frac{\sin(kq\pi \pm \alpha)}{q\sin[(kq\pi \pm \alpha)/q]} = (-1)^{k(q-1)}\frac{\sin\alpha}{q\sin(\alpha/q)}$$

that is, $$f(\theta) = (-1)^{k(q-1)}f(\alpha) \quad . \quad . \quad . \quad . \quad . \quad (7)$$

It is only necessary to use numerical values of $f(\alpha)$ covering the range $\alpha = 0$ to $\alpha = q\pi/2$, the arbitrary integer k being so chosen that α does not exceed $q\pi/2$. The curves of Fig. 3, extending to $\alpha = 6\pi$, thus indicate all numerical variations of the distribution factor for $q = 2$ to $q = 12$, inclusive.

In a great many problems the summation required is that of an infinite number of infinitely small vectors, uniformly spaced over the angle of 2θ. In electrical machinery, for example, such a case arises in the calculation of the electromotive force or the magnetomotive force of a uniformly distributed winding.* Putting q equal to infinity in Equation (1) gives for this case the special form †

$$f'(\theta) = \sin\theta/\theta \quad . \quad . \quad . \quad . \quad . \quad (8)$$

representing the ratio of the chord to the arc of an angle 2θ. There is now only one unity maximum—namely when $\theta = 0$—followed by an infinite series of continually diminishing oscillations of alternately positive and negative signs (see Fig. 3). The ordinates at the points where θ is an odd multiple of $\pi/2$ are simply

* S. P. Smith and R. S. H. Boulding, *loc. cit.*, p. 208.

† The late Prof. S. P. Thompson proposed to call the function $f'(\theta)$ "cursine θ" (see *Journal I.E.E.*, 1915, vol. 53, p. 240).

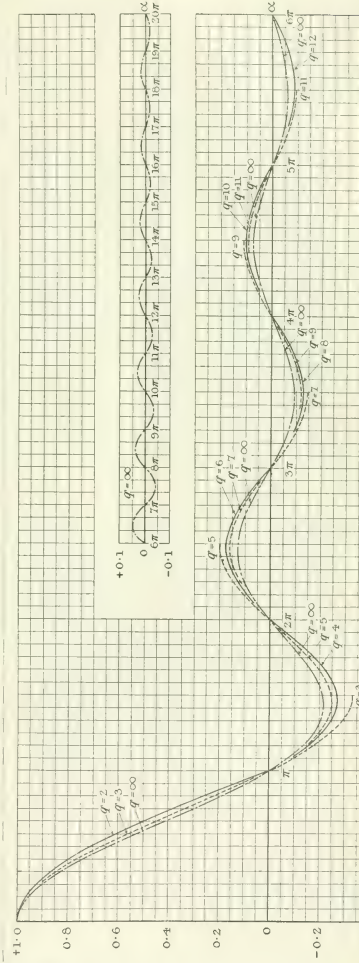

Fig. 3.—Distribution factor $f(\alpha)$ as a function of α, for various values of q (coils per group).

Note.—$\alpha = \pm(\theta - kq\pi)$; where $\theta = m\pi/2$, m = order of harmonic, α = a regular phase-spread, and k = any integer or 0.

2 (1, $\frac{1}{3}$, $\frac{1}{5}$, etc.)$f\pi$; while the true maxima occur at the values of θ which are the roots of the equation

$$\tan\theta = \theta \quad . \quad . \quad . \quad . \quad . \quad (9)$$

at which points $f(\theta) = \cos\theta$. The first few roots are approximately $\theta = 0, 1{\cdot}43\pi, 2{\cdot}46\pi, 3{\cdot}47\pi, 4{\cdot}48\pi, 5{\cdot}49\pi,$ etc., corresponding to which $f(\theta) = \cos\theta = 1{\cdot}0, 0{\cdot}2172, 0{\cdot}1284, 0{\cdot}0918, 0{\cdot}0709, 0{\cdot}0580,$ etc.

When $q = \infty$, clearly $\theta = \alpha$. In Fig. 3 the curve $f'(\alpha)$, as far as $\alpha = 6\pi$, is shown by a chain-dotted line, and is extended to $\alpha = 20\pi$ in a separate curve.

It will be seen that the curve for $q = 12$ differs only slightly from that for $q = \infty$, up to $\alpha = 6\pi$. For higher values of q the difference is still less,* up to the maximum value of α in each case (namely $\alpha = q\pi/2$). Thus, in dealing with values of q greater than 12, the practical procedure is to determine α from θ, using the actual value of q, and to read off $f(\alpha)$ from the curve for $q = \infty$.

In the particular application of the foregoing results to an armature winding, the summation required is that of the electromotive force or the magnetomotive force of a number of similar equally spaced coils, constituting a phase-group in the winding. The quantity q

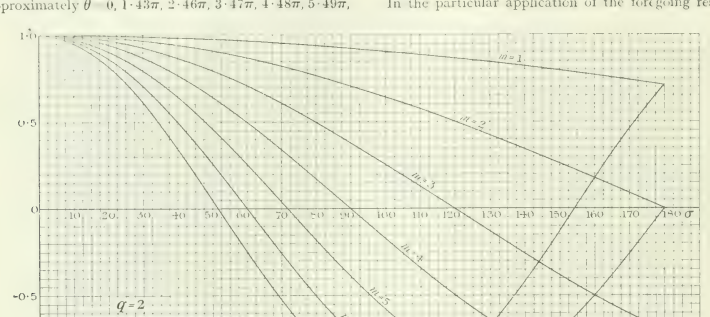

FIG. 4 (*a*).—Distribution factor for $q = 2$ coils per group, as a function of σ (angular phase-spread), for various values of m (order of harmonic).

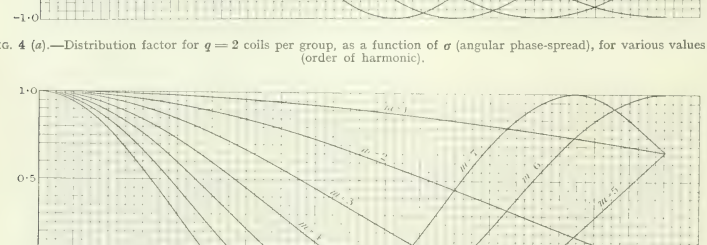

FIG. 4 (*b*).—Distribution factor for $q = 3$ coils per group, as a function of σ (angular phase-spread), for various values of m (order of harmonic).

* The greatest difference occurs at $\alpha = q\pi/2$. Taking the worst case, the respective values at $\alpha = 6\frac{1}{2}\pi$ for $q = 13$ and $q = \infty$ are $1/13 = 0{\cdot}077$ and $2/13\pi = 0{\cdot}049$, the difference amounting to $0{\cdot}028$.

is then the number of coils in the group *; and the variable θ is equal to $m\sigma/2$, where σ is the total angular spread of the group (or the peripheral arc occupied by the complete group)—which is equal to q times the angular pitch of the coils (or the peripheral distance between successive coils in series), all angles being expressed in terms of the double pole-pitch as 2π; m

Tables have previously been published * giving the numerical value of the distribution factor over a wide range of m and q, but only for a few common values of σ. Since σ cannot exceed π, Fig. 3 covers all values of m up to 12 in all cases, and much higher harmonics in most ordinary windings. The only higher values of any importance are readily dealt with by Equation (6).

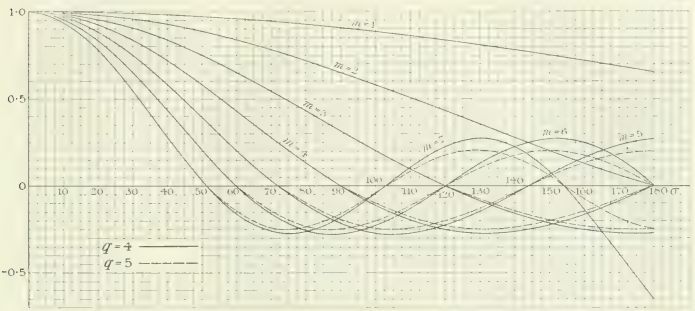

FIG. 4 (*c*).—Distribution factor for $q = 4$ and 5 coils per group, as a function of σ (angular phase-spread), for various values of m (order of harmonic).

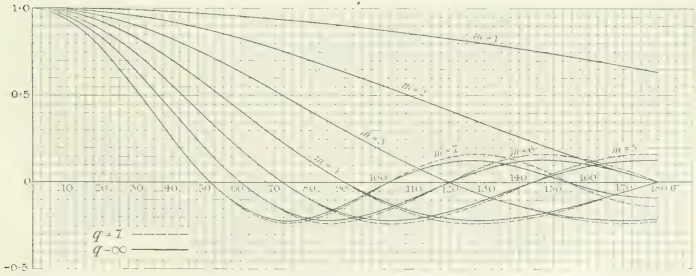

FIG. 4 (*d*).—Distribution factor for $q = 7$ and ∞ coils per group, as a function of σ (angular phase-spread), for various values of m (order of harmonic).

is the order of a particular harmonic in the space distribution of the flux or magnetomotive force under consideration.

* It will be evident that in this discussion q, being simply a number of vectors, must be integral; and in the application of these results to electrical windings, therefore, q denotes an integral number of coils (or other identical and equally spaced portions of a winding) treated as forming a group; and corresponds with the common quantity "slots per pole per phase" only when this latter is integral.

For practical purposes it is, however, usually more convenient to consider q as a known dimension of the machine, and to regard the distribution factor as a function of σ, involving m as an integral parameter.

* S. P. SMITH and R. S. H. BOULDING, *loc. cit.*, Table 1 for $\sigma = \pi/6$, $\pi/3$, $2\pi/3$, and π; $q = \infty$, and $m = 1$ to 25 (odd); Table 3 for $\sigma = \pi/3$, $q = 2$ to 10 inclusive and ∞, $m = 1$ to 65 (odd). B. HAGUE, *loc. cit.*, Tables 1, 2, and 3 for $\sigma = \pi/3$, π, and $2\pi/3$ respectively, $q = 2$ to 10 inclusive and ∞, $m = 1$ to 65 (odd) in each case.

The more important curves of Fig. 3 have therefore been separately extended to a base of σ in Figs. 4 (*a*) to 4 (*d*), for all values of m from 1 to 7 inclusive. For any one value of q the curves are, of course, of the same shape for all values of m, both odd and even, and differ only in the horizontal scales to which they are plotted; but such curves serve to show the simultaneous effect of the distribution factor upon the various orders of harmonics in particular windings. The values of m illustrated have been strictly limited to the most frequent practical requirements in order to avoid undue confusion of the diagrams. For harmonics higher than the 7th, the factor is to be taken from Fig. 3 after calculating the appropriate value of $\alpha = \pm(\theta - kq\pi)$, where $\theta = m\sigma/2$ (see page 863).

Example.—A star-connected three-phase alternator has a concentric coil winding with 12 slots per pole. Find the distribution factor for the fundamental, the important lower harmonics (3rd, 5th and 7th), the tooth ripple (23rd and 25th harmonics), and for an arbitrary higher harmonic (such as the 43rd), in the pressure-wave between terminals.

The group of coils included between a pair of terminals consists of two phases in series, and occupies two-thirds of the pole-pitch; that is $\sigma = 2\pi/3 = 120°$, and $q = 8$.

(i) For the fundamental, $m = 1$, from the curve marked "$m = 1$" in Fig. 4 (*d*), $f_1(120°) = 0{\cdot}825$.

(ii) For the 3rd harmonic, $m = 3$, using the curve marked "$m = 3$," $f_3(120°) = 0$.

(iii) For the 5th harmonic, $m = 5$, using the pair of curves marked "$m = 5$," and estimating a position representing $q = 8$ between the curves given for $q = 7$ and $q = \infty$ (nearer to the former), $f_5(120°) = -0{\cdot}18$.

(iv) For the 7th harmonic, $m = 7$, proceeding in the same manner with the curve "$m = 7$," $f_7(120°) = 0{\cdot}135$.

(v) For the tooth ripple, $m = 23$ or 25, the appropriate curves are not found in Fig. 4 (*d*). We have, however, $\theta = m\sigma/2 = 23$ (or 25)$\pi/3$; therefore $\alpha = \pm(\theta - kq\pi) = \pm[23$ (or 25) $(\pi/6) - 4k\pi]$. Taking $k = 1$, $\alpha = \pi/3$; and from Fig. 3, using curve $q = \infty$ (which here differs inappreciably from the curve for $q = 8$), $f(\pi/3) = 0{\cdot}825$. Therefore $f(\theta) = (-1)^{1(8-1)}f(\alpha) = -0{\cdot}825$. This is the same as for the fundamental, but of opposite sign.

(vi) For the high harmonic, $m = 43$, $\theta = 43\pi/3$, and $\alpha = \pm(43\pi/3 - 8k\pi)$. It is now necessary to take $k = 2$, giving $\alpha = 5\pi/3$; and from Fig. 3, estimating the reading for $q = 8$ between the curves given for $q = 5$ and $q = \infty$, $f_{43}(5\pi/3) = -0{\cdot}18$. Finally, $f(\theta) = (-1)^{2(8-1)}f(\alpha) = -0{\cdot}18$.

In conclusion, the authors wish to thank Professor S. P. Smith for his friendly criticism of the paper in its earlier stages, and Mr. A. B. Field for a suggestion leading to a material simplification of the treatment.

A UNIVERSAL "CHART" METHOD OF CALCULATING STARTING RHEOSTATS FOR DIRECT-CURRENT MOTORS.*

By A. T. Dover, Member.

(*Paper first received* 13*th December*, 1921, *and in final form* 22*nd May*, 1922.)

Summary.

The calculation of the resistances of the sections of a starting rheostat for a series motor requires a knowledge of the magnetization curve of the motor, as well as a determination of two "grading" coefficients (of which one depends on the variation of flux, and the other on the variation of current, during starting). A number of graphical and analytical methods of calculation have been proposed, but these give the solution only for a particular number of sections. The method presented in this paper has the same order of accuracy as analytical methods, but it enables the grading coefficients corresponding to several numbers of sections to be obtained simultaneously from a single set of preliminary calculations, which are considerably simpler than those required with other analytical methods. The basis of the method is the use of charts of grading coefficients which are calculated for various numbers of sections, definite values of the percentage pressure-drop in the motor at full load, and given starting conditions. The grading coefficients for any particular motor are obtained by plotting on the appropriate chart a magnetization characteristic of the motor and determining the intersection of this curve with the appropriate curves on the chart. The complete calculation of a starter can be carried out in a few minutes. The method is particularly suitable for rheostat design departments, as the charts are of universal application. Charts of grading coefficients are given for all practical requirements for industrial control and also for series-parallel control. A number of worked examples are included, illustrating the application of the method.

(1) Introduction.

The calculation of the resistances of the sections of a starting rheostat for a shunt motor is a simple matter, as the supply pressure and flux may both be assumed to be constant during starting. Under these conditions it is easy to show that for uniform current peaks and equal variations of current to occur on the several steps of the starter, the values of resistance in circuit on these steps form a geometrical series. When the flux varies during the starting period (as is the case with series and compound motors), however, the calculations are more involved, as the variation of flux with the starting current must be taken into account. In these cases it can readily be shown that, with constant supply pressure, uniform current peaks and equal variations of current on the several steps of the starter, the values of the resistances of the sections of the rheostat also form a geometrical series.

The determination of the values of these resistances, however, is not a simple matter, as a knowledge of the variations of both current and flux is necessary. In order to avoid the tediousness of a trial-and-error solution a number of purely graphical and combined analytic-graphical methods have been developed.*

The analytical methods possess the disadvantage that preliminary calculations and plotting are necessary to obtain the values of the variable quantities, and these calculations give the solution only for a particular number of sections or steps. Hence, if the number of steps in the starter is changed, a completely new set of preliminary (as well as general) calculations is necessary to obtain the grading for the new conditions. Graphical methods obviously give the solution only for a particular number of sections.

The object of this paper is to present a method in which the grading coefficients corresponding to several numbers of steps can be obtained from a single set of preliminary calculations, which are considerably simpler than those required with other analytical methods. The basis of the method is the use of charts of "grading" coefficients, calculated for various numbers of sections, definite values of the percentage pressure-drop in the motor at full load, and given (or prescribed) starting conditions. The grading coefficients corresponding to any particular motor and number of sections are obtained by plotting on the appropriate chart (or preferably on a sheet of tracing paper placed over the chart) a magnetization characteristic of the motor, and determining the point of intersection of this curve with the appropriate curve on the chart. Coefficients for other numbers of sections may also be obtained at the same time. The resistances of the sections are calculated by substituting these coefficients in simple equations, and the complete calculation of a starter can be carried through in a few minutes. The method is particularly suitable for rheostat design departments, as the charts can be applied to all types of direct-current motors. It may be of interest to note that the principle of applying these charts to the calculation of the grading of starters for series motors was developed from the special case of starters for shunt motors, and for this reason it will, perhaps, be better to consider briefly first the theory of starting rheostats for shunt motors before considering the general theory relating to series and compound motors.

* The Papers Committee invite written communications (with a view to publication in the *Journal* if approved by the Committee) on papers published in the *Journal* without being read at a meeting. Communications should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

* A number of these methods have been developed with particular reference to the series-parallel control of traction motors, and are discussed in the author's "Electric Motors and Control Systems," page 268. An analytical method is also given in *Journal I.E.E.*, 1920, vol. 58, p. 645.

(2) Theory. Special Case of Starter for a Shunt Motor.

When a shunt motor is started in the ordinary way by inserting resistance in the armature circuit, the flux may be considered to be constant during the

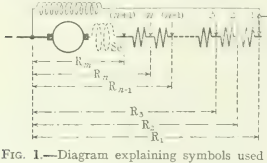

Fig. 1.—Diagram explaining symbols used in the paper.

starting period if the supply pressure is maintained constant.

Let V = supply pressure (assumed to be constant);
I_1 = upper limit of current during starting;
I_2 = lower limit of current during starting;
$R_1, R_2, \ldots R_n$ = resistances of the armature circuit (i.e. starter and armature) corresponding to the several steps of the starter (see Fig. 1);
n = number of sections in starter, the number of steps or notches being $(n + 1)$; and
R_m = resistance of armature (and commutating field winding, if any).

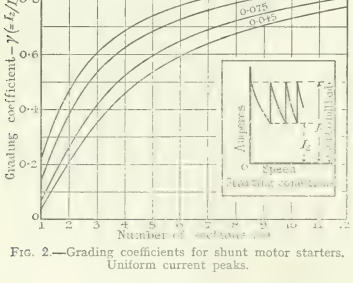

Fig. 2.—Grading coefficients for shunt motor starters. Uniform current peaks.

Then, if the initial current peak is equal to the succeeding ones, $R_1 = V/I_1$, since the speed is zero when switching on.

When the armature current falls to its lower limit, I_2, the resistance, R_1, of the armature circuit is changed to a lower value, R_2: and, since the speed and counter E.M.F., E_1, are unchanged, we have

$$E_1 = V - I_2R_1 = V - I_1R_2$$

Hence $I_2R_1 = I_1R_2$,

or $$R_2 = (I_2/I_1)R_1 = \gamma R_1 \quad . \quad . \quad . \quad [1(a)]$$

where $\gamma = I_2/I_1$. (*Note.*—γ may be called the "grading" coefficient, as its value determines the grading of the resistance sections of the starter.)

Similarly, $R_3 = (I_2/I_1)R_2 = (I_2/I_1)^2R_1 = \gamma^2R_1$. [1(b)]

and $R_n = (I_2/I_1)R_{n-1} = (I_2/I_1)^{n-1}R_1 = \gamma^{n-1}R_1$ [1(n)]

When the last section $(R_n - R_m)$ of the starting resistance is cut out, we have

$$E_n = V - I_2R_n = V - I_1R_m$$

whence $R_m = (I_2/I_1)R_n = (I_2/I_1)^nR_1 = \gamma^nR_1$

Hence $$R_m/R_1 = \gamma^n \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Now R_m can be expressed in terms of the pressure-

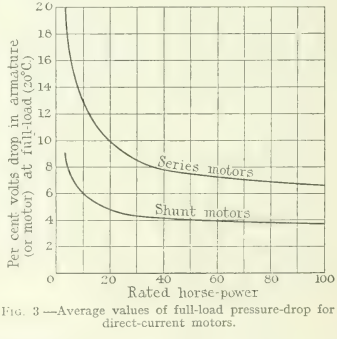

Fig. 3.—Average values of full-load pressure-drop for direct-current motors.

drop, e, in the motor at full-load current I. Thus $R_m = e/I$, and, since $R_1 = V/I_1$, we have

$$\frac{R_m}{R_1} = \frac{e}{V}\cdot\frac{I_1}{I} \quad . \quad . \quad . \quad . \quad (3)$$

Hence $$\gamma = \sqrt[n]{\left(\frac{e}{V}\cdot\frac{I_1}{I}\right)} = \sqrt[n]{\left(\frac{v}{100}\cdot\frac{I_1}{I}\right)} \quad . \quad . \quad . \quad (4)$$

where v is the percentage pressure-drop in the motor at full load.

By choosing definite values for v and I_1/I we can calculate values of γ for various numbers of sections n. The results are plotted as shown in Fig. 2, which gives curves for $I_1/I = 1{\cdot}5$, and $v = 3$, 5, 10 and 15 per cent. Additional curves may be added, if necessary, for other values of v, but sufficient accuracy is obtained for practical purposes by interpolation when the value of v differs from those for which the curves are drawn.

We have, therefore, a means of obtaining directly the value of the grading coefficient when n, v, and I_1/I are known. Appropriate values of v for shunt

and series motors are given in Table 1 and Fig. 3. For face-plate starters I_1/I is usually 1·5, as specified in the British Engineering Standards Association Specification No. 82.

When γ is known, the resistances of the sections $R_1 - R_2$, $R_2 - R_3$, etc., are obtained from Equations [1(*a*)] to [1(*n*)].

Thus $R_1 - R_2 = R_1 - \gamma R_1 = R_1(1 - \gamma)$. [5(*a*)]

$$R_2 - R_3 = \gamma R_1 - \gamma^2 R_1 = R_1\gamma(1 - \gamma) = \gamma(R_1 - R_2). \quad [5(b)]$$

$$R_3 - R_4 = \gamma^2 R_1 - \gamma^3 R_1 = R_1\gamma^2(1 - \gamma) = \gamma(R_2 - R_3). \quad [5(c)]$$

Etc.

This method of obtaining the value of the grading coefficient can be extended to include the cases where (*a*) the initial starting current must be lower than the maximum current peak I_1, and (*b*) the mean starting current is to be equal to full-load current (or a prescribed percentage of full-load current), the initial current peak being either equal to or lower than the succeeding peaks. These cases are readily developed from the general case considered on page 874.

(3) General Theory.

If, with the conditions assumed on page 868, we have the additional condition that the flux varies with the armature current—having the values Φ_1, Φ_2 at the currents I_1, I_2, respectively—then, neglecting the effects of inductance, the change of current from I_1 to I_2, due to the cutting out of a section of the starting resistance, will cause the counter E.M.F. to change from $k\Phi_2$ to $k\Phi_1$.

Hence $V - I_2R_1 = k\Phi_2$ and $V - I_1R_2 = k\Phi_1$

whence $$\frac{k\Phi_2}{k\Phi_1} = \frac{V - I_2R_1}{V - I_1R_2}$$

that is $$\frac{\Phi_2}{\Phi_1} = \frac{V - I_2R_1}{V - I_1R_2}$$

and generally,

$$\frac{\Phi_2}{\Phi_1} = \frac{V - I_2R_1}{V - I_1R_2} = \frac{V - I_2R_2}{V - I_1R_3} = \ldots = \frac{V - I_2R_n}{V - I_1R_m}. \quad (6)$$

where R_m is the resistance of the armature and series field windings.

Dividing the numerators by I_2, and the denominators by I_1, we obtain

$$\frac{\Phi_2}{\Phi_1}\cdot\frac{I_1}{I_2} = \frac{VI/I_2 - R_1}{VI/I_1 - R_2} = \frac{VI/I_2 - R_2}{VI/I_1 - R_3} = \ldots = \frac{VI/I_2 - R_n}{VI/I_1 - R_m} \quad (7)$$

Now $VI/I_1 = R_1$, and VI/I_2 may be written as R_0, which represents the total resistance necessary to obtain the current I_2 when the speed is zero. (*Note* :— $R_0 = R_1(I_1/I)_2 = R_1/\gamma$, where $\gamma = I_2/I_1$, as above.)

Hence, writing λ for $\Phi_1 I_2/\Phi_2 I_1$, Equations (7) reduce to

$$\frac{1}{\lambda} = \frac{R_0 - R_1}{R_1 - R_2} = \frac{R_0 - R_2}{R_1 - R_3} = \ldots = \frac{R_0 - R_n}{R_1 - R_m} \quad (8)$$

Whence $R_1 - R_2 = \lambda(R_0 - R_1) = \lambda(R_1/\gamma - R_1) = R_1\lambda(1 - \gamma)/\gamma$ . . . [9(*a*)]

$$R_1 - R_3 = \lambda(R_0 - R_2) = \lambda(R_1/\gamma - R_2)$$

. . . . . .

$$R_1 - R_m = \lambda(R_0 - R_n) = \lambda(R_1/\gamma - R_n)$$

Table 1.

Values of v (percentage volts drop in armature, or motor, circuit at full load 20° C.) for Shunt and Series Motors.

Rated horse-power *	3	5	10	20	35	50	75	100
v (shunt motors)	9	7·3	5·8	4·8	4·2	4	3·8	3·5
v (series motors)	20	16	12·8	10	8	7·5	7	6·5

* The rated horse-power refers to the *continuous* rating of the shunt motors, and to the *intermittent* rating of the series motors.

From these equations we obtain by successive subtraction and substitution

$$R_2 - R_3 = \lambda\{(R_0 - R_2) - (R_0 - R_1)\} = R_1\lambda^2(1 - \gamma)/\gamma \quad [9(b)]$$

$$R_3 - R_4 = \lambda\{(R_0 - R_3) - (R_0 - R_2)\} = R_1\lambda^3(1 - \gamma)/\gamma \quad [9(c)]$$

. . . . . .

$$R_n - R_m = \lambda\{(R_0 - R_n) - (R_0 - R_{n-1})\} = R_1\lambda^n(1 - \gamma)/\gamma \quad [9(n)]$$

We see, therefore, that two "grading" coefficients (γ, λ) are involved in the determination of the resistances of the sections. The value of the coefficient λ depends on the slope of the magnetization curve of the motor between the current limits I_1, I_2, and is given by the ratio of the tangents of the angles formed by drawing lines from the origin to two points on the curve, representing the lower and upper limits of current, respectively, i.e. $\lambda = (\Phi_1/I_1)/(\Phi_2/I_2)$. In the case of a purely unsaturated magnetic circuit $\lambda = 1{\cdot}0$, and in the other extreme case when the flux is constant $\lambda = \gamma$. Hence, if we substitute $\lambda = \gamma$ in Equations [9(*a*)] to [9(*n*)] we obtain equations identical with those deduced for the case of a shunt motor.

To determine λ and γ for any particular motor, and given starting conditions, we proceed in the following

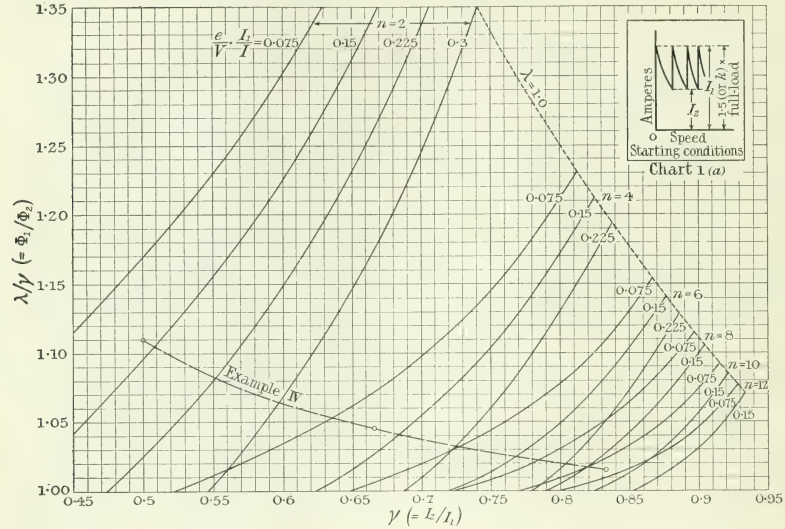

FIG. 4.—Chart for determining grading coefficients for series motor starters having 2–12 sections. Uniform current peaks.

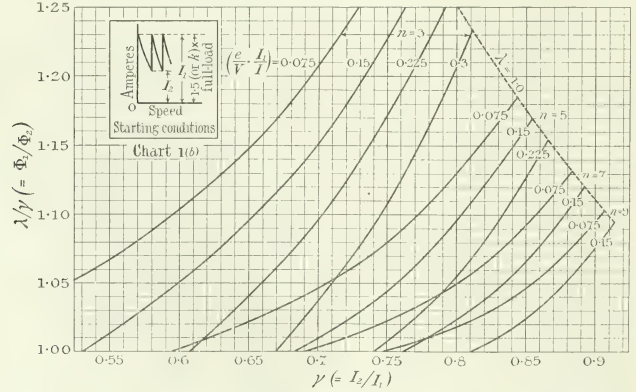

FIG. 4A.—Chart for determining grading coefficients for series motor starters having 3–9 sections. Uniform current peaks.

manner. By addition of Equations [9(*a*)] to [9(*n*)] we have

$$R_1 - R_m = R_1\{(1-\gamma)/\gamma\}\{\lambda + \lambda^2 + \ldots + \lambda^n\}$$
$$= R_1\left(\frac{1-\gamma}{\gamma}\right)\lambda\left(\frac{1-\lambda^n}{1-\lambda}\right)$$

and by transposing and re-arranging, we obtain

$$\frac{R_m}{R_1} = \left\{1 - \frac{\lambda}{\gamma}\left(\frac{1-\gamma}{1-\lambda}\right)(1-\lambda^n)\right\} \quad . \quad . \quad (10)$$

Now we have shown (see page 868) that $R_m/R_1 = (e/V)(I_1/I)$. Hence the grading coefficients may be expressed in terms of the definite quantities e/V, I_1/I and n. Thus from Equation (10)

$$\frac{\lambda}{\gamma}\left(\frac{1-\gamma}{1-\lambda}\right)(1-\lambda^n) = 1 - \frac{e}{V}\frac{I_1}{I}$$

whence

$$\frac{1}{\gamma} = 1 + \frac{1 - (e/V)(I_1/I)}{\lambda(1-\lambda^n)/(1-\lambda)} \quad . \quad . \quad (11)$$

By assuming values for λ we can calculate values of γ corresponding to definite values of n, e/V and I_1/I. To facilitate these calculations, values of the denominator—$\lambda(1-\lambda^n)/(1-\lambda)$—corresponding to values of λ/γ and γ for any particular number of sections n.

(4) Examples. Calculation of Starting Resistance for 7½-h.p. Series Motors.

In order to illustrate the application of the method, let us consider two cases: (1) a 440-volt motor controlled by a 5-point drum controller; and (2) a 220-volt motor controlled by a 3-point automatic starter. Both motors have similar magnetic circuits and operate at the same full-load speed and flux, the designs differing only in the windings, commutators and brush-gear. The saturation curve for both motors is given in Fig. 5. The percentage pressure-drop at full load is 15 per cent in each case. Hence the curves in Chart 1(*a*), Fig. 4, can be used without interpolation.*

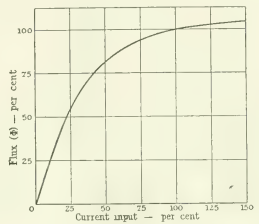

Fig. 5.—Magnetization curve of 7½-h.p. series motors (for examples calculated in Section 4).

Table 2.

Values of $\lambda(1-\lambda^n)/(1-\lambda)$ *for Various Values of* λ *and* n.

Values of n	2	3	4	5	6	7	8	9	10	11	12
Values of λ	$\lambda(1-\lambda^n)/(1-\lambda)$										
0·5	0·75	0·875	0·9375	—	—	—	—	—	—	—	—
0·6	0·96	1·176	1·306	1·383	1·43	1·458	1·475	1·485	—	—	—
0·7	1·19	1·533	1·773	1·941	2·058	2·141	2·198	2·239	—	—	—
0·75	1·312	1·734	2·051	2·288	2·466	2·6	2·7	2·775	2·831	2·873	2·905
0·8	1·44	1·952	2·362	2·689	2·951	3·161	3·329	3·463	3·57	3·656	3·725
0·85	1·572	2·187	2·708	3·152	3·529	3·845	4·122	4·354	4·551	4·718	4·86
0·9	1·71	2·439	3·095	3·685	4·217	4·695	5·106	5·513	5·862	6·176	6·458
0·95	1·852	2·71	3·524	4·298	5·033	5·732	6·395	7·025	7·624	8·193	8·733
1·0	2·0	3·0	4·0	5·0	6·0	7·0	8·0	9·0	10·0	11·0	12·0

selected values of λ and n, are given in Table 2. Thence we calculate λ/γ and plot λ/γ against γ, thereby obtaining curves for each selected value of e/V and for each value of n. Specimen charts are given in Figs. 4 and 4A.*

If we now superimpose upon the chart a curve, drawn to the same scale, connecting λ/γ (i.e. Φ_1/Φ_2) and γ (i.e. I_2/I_1) for the particular motor, then the intersection of this curve with the curves on the chart for the appropriate value of e/V will give the required values of λ/γ and γ for any particular number of sections n.

To obtain the relationship between λ/γ and γ from the saturation curve, select $I_1 = 150$ per cent, $I_2 = 125$, 100 and 75 per cent; obtain from the curve the corresponding values of the flux; and calculate I_2/I_1, and Φ_1/Φ_2. Thus:—

* Alternate values of n are shown in the two figures in order to prevent confusion due to overlapping of the curves, which may occur when all curves are drawn on one chart. In practice, however, all curves could be drawn on one chart, as individual curves could be coloured to prevent confusion where overlapping occurs.

* For motors up to 7½ h.p. the upper limit of current during starting may be taken as being 150 per cent of the full-load current.

I_1 (per cent)	150	150	150
I_2 (per cent)	125	100	75
$I_2/I_1(=\gamma)$	0·833	0·666	0·5
Φ_1 (per cent)	104·5	104·5	104·5
Φ_2 (per cent)	103	100	94
$\Phi_1/\Phi_2\ (=\lambda/\gamma)$	1·015	1·045	1·111

By plotting λ/γ and γ on Chart 1(*a*) we obtain (see Fig. 4) the points of intersection with the appropriate $(e/V)(I_1/I)$ curves (corresponding in this case to $0{\cdot}15 \times 1{\cdot}5 = 0{\cdot}225$) as

$\gamma = 0{\cdot}725$; $\lambda/\gamma = 1{\cdot}033$ ($\therefore \lambda = 0{\cdot}748$) for $n = 4$; and
$\gamma = 0{\cdot}551$; $\lambda/\gamma = 1{\cdot}082$ ($\therefore \lambda = 0{\cdot}596$) for $n = 2$.

For the 440-volt motor and the 5-point starter ($n = 4$) the full-load current = 16 amperes, and the resistance of the motor = $R_m = 0{\cdot}15 \times 440/16 = 4{\cdot}12$ ohms. Hence $I_1 = 1{\cdot}5 \times 16 = 24$ amperes ; $I_2 = 0{\cdot}725 \times 24 = 17{\cdot}4$ amperes ; and $R_1 = 440/24 = 18{\cdot}3$ ohms. The total resistance of the starting rheostat is therefore $R_1 - R_m = 18{\cdot}3 - 4{\cdot}12 = 14{\cdot}18$ ohms, which is divided as follows :—

$$R_1 - R_2 = R_1\lambda/\gamma(1-\gamma) = 18{\cdot}3 \times 1{\cdot}033(1 - 0{\cdot}725) = 5{\cdot}2 \text{ ohms}$$
$$R_2 - R_3 = \lambda(R_1 - R_2) = 0{\cdot}748 \times 5{\cdot}2 = 3{\cdot}89 \text{ ohms}$$
$$R_3 - R_4 = \lambda(R_2 - R_3) = 0{\cdot}748 \times 3{\cdot}89 = 2{\cdot}91 \text{ ohms}$$
$$R_4 - R_5 = \lambda(R_3 - R_4) = 0{\cdot}748 \times 2{\cdot}91 = 2{\cdot}18 \text{ ohms}$$
$$\text{Total} \quad .. \quad 14{\cdot}18 \text{ ohms}$$

For the 220-volt motor and the 3-point starter ($n = 2$) the full-load current = 32 amperes, and the resistance of the motor = $R_m = 0{\cdot}15 \times 220/32 = 1{\cdot}03$ ohms. Hence $I_1 = 1{\cdot}5 \times 32 = 48$ amperes ; $I_2 = 0{\cdot}551 \times 48 = 26{\cdot}5$ amperes ; and $R_1 = 220/28 = 4{\cdot}58$ ohms.

The total resistance of the starter $= R_1 - R_m = 4{\cdot}58 - 1{\cdot}03 = 3{\cdot}55$ ohms, which is divided as follows :—

$$R_1 - R_2 = R_1\lambda/\gamma(1-\gamma) = 4{\cdot}58 \times 1{\cdot}082\,(1 - 0{\cdot}551) = 2{\cdot}225 \text{ ohms}$$
$$R_2 - R_3 = \lambda(R_1 - R_2) = 0{\cdot}596 \times 2{\cdot}225 = 1{\cdot}325 \text{ ohms}$$
$$\text{Total} \quad .. \quad .. \quad .. \quad 3{\cdot}55 \text{ ohms}$$

Provided that the starting conditions are unaltered, grading coefficients for other numbers of sections may be obtained directly from the charts * (Figs. 4, 4A) without further calculation. Thus

$n = 2$; $\gamma = 0{\cdot}551$; $\lambda/\gamma = 1{\cdot}082$; $\lambda = 0{\cdot}596$.
$n = 3$; $\gamma = 0{\cdot}658$; $\lambda/\gamma = 1{\cdot}048$; $\lambda = 0{\cdot}69$.
$n = 4$; $\gamma = 0{\cdot}725$; $\lambda/\gamma = 1{\cdot}033$; $\lambda = 0{\cdot}748$.
$n = 5$; $\gamma = 0{\cdot}77$; $\lambda/\gamma = 1{\cdot}024$; $\lambda = 0{\cdot}788$.
$n = 6$; $\gamma = 0{\cdot}803$; $\lambda/\gamma = 1{\cdot}02$; $\lambda = 0{\cdot}82$.

* Special care has been taken in reproducing the charts (Figs. 4, 4A, 6, 6A, 8, 8A, 10, 10A) to ensure that all co-ordinates are shown to the same scale. The sheet of tracing paper, on which is plotted the $\Phi_1/\Phi_2 = I_2/I_1$ curve for the particular motor, may therefore be used with any chart provided that this curve has been calculated for the starting conditions appropriate to that chart. For example, a curve calculated for Charts 1 (*a*), 1 (*b*) may be used with Charts 2 (*a*), 2 (*b*) as shown in Section 5. Similarly, a curve calculated for Charts 3 (*a*), 3 (*b*) may be used with Charts 4 (*a*), 4 (*b*), and vice versâ.

But if the upper limit of current is changed to, say, 125 per cent of full-load current, $(e/V)(I_1/I)$ is now equal to $0{\cdot}15 \times 1{\cdot}25 = 0{\cdot}1875$, and interpolation between the $0{\cdot}15$ and $0{\cdot}225$ curves is necessary. It is also necessary to re-calculate the new relationship between Φ_1/Φ_2 and I_2/I_1.

It is important to observe that when the grading coefficients are known the grading of the sections of the starters may be determined once for all and expressed in percentages of the total resistance R_1. Thus for the cases considered above—

	Resistances of Sections (in per cent of total resistance R_1)					
n	$R_1 - R_2$	$R_2 - R_3$	$R_3 - R_4$	$R_4 - R_5$	$R_5 - R_6$	$R_6 - R_7$
2	48·6	28·9	—	—	—	—
3	35·8	24·7	17·0	—	—	—
4	28·4	21·3	15·9	11·9	—	—
5	23·5	18·6	14·7	11·6	9·1	—
6	20·1	16·5	13·5	11·0	9·0	7·4

(5) Special Starting Conditions: (A) Initial Starting Current Lower than Upper Limit. (B) Mean Starting Current Equal to Full-load Current.

The general principle deduced in Section (3) may be extended to include special starting conditions.

Condition (A).—First consider the case when the initial starting current is to be lower than the upper limit of current I_1. Let I_0 be the initial starting current, and let $I_1/I_0 = \zeta$. Then if the resistances in circuit on the several steps are R_1', R_2', ... R_n', and the other conditions are as above, we have

$$R_1' = V/I_0$$

$$\frac{\Phi_2}{\Phi_1} = \frac{V - I_2R_1'}{V - I_1R_1'} = \frac{V - I_2R_2'}{V - I_1R_2'} = \ldots = \frac{V - I_2R_n'}{V - I_1R_m'} \quad . \quad (12)$$

Whence

$$\frac{\Phi_2}{\Phi_1}\cdot\frac{I_1}{I_2} = \frac{VI_2 - R_1'}{VI_1 - R_1'} = \frac{VI_2 - R_2'}{VI_1 - R_2'}$$
$$= \ldots = \frac{VI_2 - R_n'}{VI_1 - R_m'} \quad . \quad (13)$$

Substituting $I_0 = V/I_2$; $R_1 = V/I_1$; and $\lambda = \frac{\Phi_1}{\Phi_2}\cdot\frac{I_2}{I_1}$

Equation (13) reduces to

$$\frac{1}{\lambda} = \frac{R_0 - R_1'}{R_1 - R_1'} = \frac{R_0 - R_2'}{R_1 - R_2'} = \ldots = \frac{R_0 - R_n'}{R_1 - R_m} \quad . \quad (14)$$

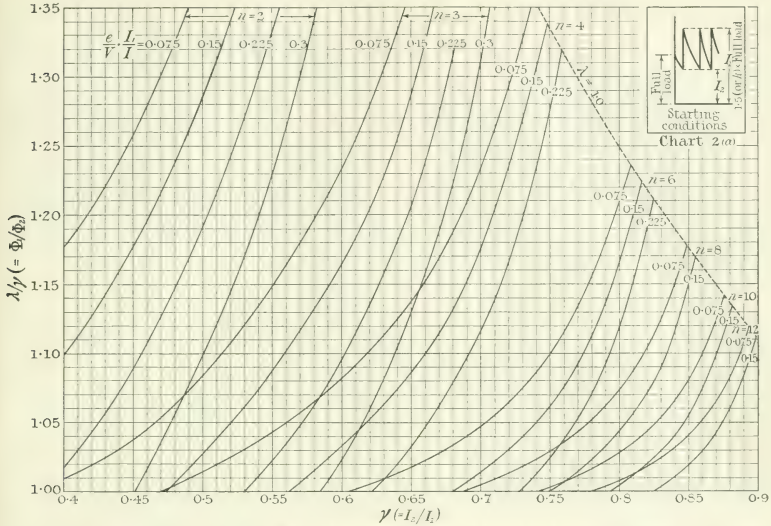

FIG. 6.—Chart for determining grading coefficients for series motor starters having 2–12 sections. Starting current equal to full-load current.

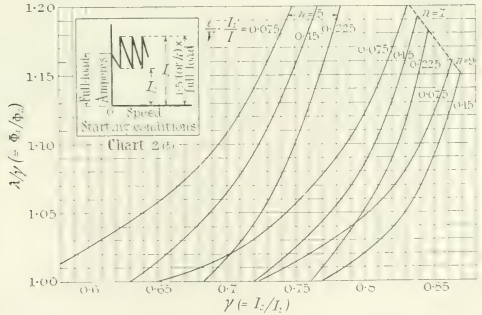

FIG. 6A.—Chart for determining grading coefficients for series motor starters having 5, 7, or 9 sections. Starting current equal to full-load current.

Whence
$$\begin{aligned} R_1 &= R'_2 = \lambda(R_0 - R'_1) \\ R_1 &= R'_3 = \lambda(R_0 - R'_2) \\ &\cdots\cdots \\ R_1 &= R_m = \lambda(R_0 - R'_n) \end{aligned}$$

If, in the first of these equations, we substitute $[R'_1 - R_1(\zeta - 1)]$ for R_1, and on the right-hand side we replace R_0 by $R_1\gamma$, and R'_1 by ζR_1, we obtain on simplification

$$R'_1 - R'_2 = R_1\left\{\lambda(1 - \zeta\gamma)/\gamma + (\zeta - 1)\right\} \quad . \quad [15(a)]$$
$$= R'_1\left\{\frac{\lambda}{\gamma}\left(\frac{1}{\zeta} - \gamma\right) + \left(1 - \frac{1}{\zeta}\right)\right\} \quad . \quad [15(a_1)]$$

By successive subtraction of the same equations (i.e. subtracting the first from the second, the second from the third, etc.) we obtain

$$R'_2 - R'_3 = \lambda(R'_1 - R'_2)$$
$$= R_1\lambda\left\{\lambda(1 - \zeta\gamma)/\gamma + (\zeta - 1)\right\} \quad . \quad [15(b)]$$
$$= R'_1\lambda\left\{\frac{\lambda}{\gamma}\left(\frac{1}{\zeta} - \gamma\right) + \left(1 - \frac{1}{\zeta}\right)\right\} \quad . \quad [15(b_1)]$$

and finally

$$R'_n - R_m = \lambda(R'_n - R'_{n-1})$$
$$= R_1\lambda^{n-1}\left\{\lambda(1 - \zeta\gamma)/\gamma + (\zeta - 1)\right\} \quad . \quad [15(n)]$$
$$= R'_1\lambda^{n-1}\left\{\frac{\lambda}{\gamma}\left(\frac{1}{\zeta} - \gamma\right) + \left(1 - \frac{1}{\zeta}\right)\right\} \quad . \quad [15(n_1)]$$

By addition of Equations $15(a)$ to $15(n)$ we have

$$R'_1 - R_m = R_1\left\{\lambda(1 - \zeta\gamma)/\gamma + (\zeta - 1)\right\}\left\{1 + \lambda + \lambda^2 + \ldots + \lambda^{n-1}\right\}$$

or

$$\zeta R_1 - R_m = R_1\left\{\lambda(1 - \zeta\gamma)/\gamma + (\zeta - 1)\right\}(1 - \lambda^n)/(1 - \lambda)$$

whence

$$\frac{R_m}{R_1} = \zeta - \left\{\frac{\lambda}{\gamma}(1 - \zeta\gamma) + (\zeta - 1)\right\}\left(\frac{1 - \lambda^n}{1 - \lambda}\right) \quad . \quad (16)$$

But
$$R_m/R_1 = (e/V)(I_1/I)$$

hence
$$\frac{e}{V}\cdot\frac{I_1}{I} = \zeta - \left\{\frac{\lambda}{\gamma}(1 - \zeta\gamma) + (\zeta - 1)\right\}\left(\frac{1 - \lambda^n}{1 - \lambda}\right)$$

from which

$$\frac{1}{\gamma} = \zeta + \frac{\zeta - (e/V)(I_1/I)}{\lambda(1 - \lambda^n)/(1 - \lambda)} - \left(\frac{\zeta - 1}{\lambda}\right) \quad . \quad (17)$$

This equation is a more general form of Equation (11), which may readily be obtained from Equation (17) by putting $\zeta = 1$.

Charts calculated from Equation (17) for $\zeta = 1{\cdot}5$ (i.e. initial starting current equal to full-load current and the upper limit of current equal to $1{\cdot}5$ times full-load current) are given in Figs. 6 and 6A.

These charts are used in the same manner as the previous ones (Figs. 4, 4A), the preliminary calculations for obtaining the relationship between Φ_1/Φ_2 and I_2/I_1 for any particular motor being identical in both cases. Hence if the curve calculated for Example IV be transferred to Figs. 6, 6A, the grading coefficients corresponding to the new starting conditions may readily be obtained. These coefficients and the grading of the sections of the starters calculated from Equations $15(a_1)$ to $15(n_1)$ are given in the subjoined table.

n	γ	λ/γ	λ	Grading (in per cent of total resistance R'_1)				
				$R'_1 - R'_2$	$R'_2 - R'_3$	$R'_3 - R'_4$	$R' - R'_5$	$R' - R'$	$R'_6 - R'_7$
2	0·471	1·129	0·531	55·5	29·5	—	—	—	—
3	0·583	1·069	0·623	42·3	26·3	16·4	—	—	—
4	0·66	1·047	0·691	34	23·5	16·3	11·2	—	—
5	0·715	1·035	0·74	28·5	21·0	15·5	11·5	8·5	—
6	0·753	1·029	0·775	24·4	18·9	14·7	11·4	8·8	6·8

In the case of a shunt motor $\lambda/\gamma = 1$, or $\lambda = \gamma$, and Equation (17) reduces to

$$\gamma = \sqrt[n]{\left(\frac{e}{V}\cdot\frac{I_1}{\zeta I}\right)} = \sqrt[n]{\left(\frac{e}{V}\cdot\frac{I_0}{I}\right)} \quad . \quad . \quad (18)$$

When the initial starting current I_0 is equal to the full-load current I, then

$$\gamma = \sqrt[n]{(e/V)} \quad . \quad . \quad . \quad . \quad [18(a)]$$

Curves calculated from this equation for a number of values of e/V and various numbers of section n are given in Fig. 7. The value of γ for given values of e/V and n is, of course, equal to that given in Charts $2(a)$ and $2(b)$ [Figs. 6 and 6A] for $\lambda/\gamma = 1{\cdot}0$ and the given values of e/V and n.

The resistances of the sections of the starter are derived from Equations (12) by putting $\Phi_2/\Phi_1 = 1$.

Thus
$$R'_1 - R'_2 = R'_1(1 - \gamma) = (V/I_0)(1 - \gamma) \quad . \quad [19(a)]$$
$$R'_2 - R'_3 = \gamma(R'_1 - R'_2) \quad . \quad . \quad . \quad . \quad . \quad [19(b)]$$
$$R'_3 - R'_4 = \gamma(R'_2 - R'_3) \quad . \quad . \quad . \quad . \quad . \quad [19(c)]$$
Etc.

Condition (*B*).—In cases where the mean value of the current during starting is to equal full-load current and the current peaks are to be uniform, let the variation of current above and below full-load current I be denoted by i, and let $i/I = \delta$. Then $I_1 = I + i$; $I_2 = I - i$; $I_1/I = 1 + i/I = 1 + \delta$; and $\gamma = I_2/I_1 = (I - i)/(I + i) = (1 - \delta)/(1 + \delta)$.

Case 1.—When the initial starting current is equal to

the upper limit I_1, Equation (11) is modified by substituting the above values for I_1/I and γ. Thus

$$\frac{1+\delta}{1-\delta} = 1 + \frac{1-(e/V)\ (1+\delta)}{\lambda(1-\lambda^n)/(1-\lambda)} \quad . \quad . \quad (20)$$

We now require to calculate values for δ corresponding to assumed values for λ and definite values for e/V. Denoting the denominator $\lambda(1-\lambda^n)/(1-\lambda)$ by α for brevity, and re-arranging the terms, we find that the simplest form of Equation (20) is

$$\frac{e}{V} = \frac{1+\alpha}{1+\delta} - \frac{\alpha}{1-\delta} \quad . \quad . \quad . \quad (21)$$

The direct solution for δ therefore involves the solution of a quadratic equation. But the numerical coefficients obtained by substituting appropriate values for e/V and α (values of α corresponding to various values of λ and

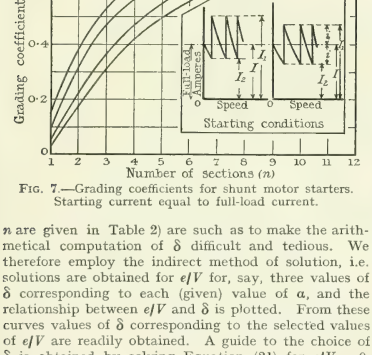

FIG. 7.—Grading coefficients for shunt motor starters. Starting current equal to full-load current.

n are given in Table 2) are such as to make the arithmetical computation of δ difficult and tedious. We therefore employ the indirect method of solution, i.e. solutions are obtained for e/V for, say, three values of δ corresponding to each (given) value of α, and the relationship between e/V and δ is plotted. From these curves values of δ corresponding to the selected values of e/V are readily obtained. A guide to the choice of δ is obtained by solving Equation (21) for $e/V = 0$, which gives $\delta_{max.} = 1/(1+2\alpha)$. Having obtained this value it is only necessary to take either one or two lower values of δ.*

When δ is determined, the corresponding value of γ is calculated; then the ratio λ/γ is calculated and plotted against γ, as in Charts 3(*a*) and 3(*b*) on Figs. 8 and 8A. The relationship between γ and δ is also shown in these charts.

The resistances of the sections are obtained (when the values of λ and γ are determined for the particular motor and number of sections †) by the application of Equations [9(*a*)] to [9(*n*)], the upper limit of current I_1 being calculated from the value of γ. Thus $I_1 = I(1+\delta) = I(1+(1-\gamma)/(1+\gamma)) = 2I/(1+\gamma)$.

* For the practical range of values of e/V the relationship between e/V and δ is a linear one.

† The method of obtaining λ and γ is given in Section 6.

In the case of a shunt motor Equation (21)—when substitutions are made for λ, α and δ (e.g. $\lambda = \gamma$; $\alpha = \gamma(1-\gamma^n)/(1-\gamma)$; $\delta = (1-\gamma)/(1+\gamma)$—reduces to

$$(1+\gamma)\gamma^n = 2e/V \quad . \quad . \quad . \quad . \quad (22)$$

which could be further reduced to $\gamma^n = (e/V)(I_1/I)$, but, since I_1/I is not known in the present case, this equation is of no use for determining the relationship between γ, n and e/V. Curves calculated from Equation (22) are given in Fig. 9.* Thus with e/V known, the value of γ corresponding to a definite number of sections n is obtained from the appropriate curve.

The upper limit of current I_1 is calculated from γ as above. The resistances of the sections then follow from Equations [5(*a*)], etc.

Case 2.—When the initial starting current must be limited to full-load current, I, Equation (17) is modified by substituting $(1+\delta)$ for both ζ and I/I_1. On simplification we obtain

$$\frac{e}{V} = 1 + \frac{\alpha}{1+\delta}\left\{1-\delta\left(\frac{1}{\lambda}-1\right)\right\} - \frac{\alpha}{1-\delta} \quad . \quad (23)$$

where $\alpha = \lambda(1-\lambda^n)/(1-\lambda)$.

Values of δ, corresponding to assumed values of λ, for given values of n and e/V are obtained as in the previous case. The final results are given in Charts 4(*a*) and 4(*b*) on Figs. 10 and 10A. The resistances of the sections are obtained by the application of Equations [15(*a*)] to [15(*n*)] as shown in the example given in Section 6.

In the case of a shunt motor Equation (23)—when substitutions are made for λ, α, δ as above—reduces to

$$\gamma^n = e/V \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

whence $$\gamma = \sqrt[n]{(e/V)}$$

a result identical with that obtained in Equation [18(*a*)]. Hence the curves of Fig. 7 are applicable to the present case. The upper limit of current is given by $I_1 = 2I/(1+\gamma)$, as above, and the resistances of the sections are obtained from Equations [19(*a*)], etc. The grading is therefore identical with that for the case when the initial starting current is to equal full-load current, and given upper and lower current limits are to be obtained on each step. The different starting conditions in the two cases are determined by the value of the lower limit of current; and by raising or lowering this limit the upper limit, and also the mean current, are raised or lowered in proportion.

(6) Example. Calculation of Starting Resistance for a 120-h.p., 460-volt Compound-wound Motor and 13-point Drum Controller. (Initial Starting Current and Mean Current during Starting Equal to Full-load Current.)

The motor is designed for a colliery haulage plant and is heavily compounded, the rise in speed from full

* The solutions of Equation (22) are best obtained graphically. The relationship between γ and γ^n, for given values of n, is plotted, and on the same sheet are plotted curves giving the relationship between γ and $2(e/V)/(1+\gamma)$ for selected values of (e/V). The intersections of these two sets of curves give the values of γ corresponding to the given values of e/V and n.

load to no load being 40 per cent of the full-load speed. The speed curve corresponding to normal supply pressure (460 volts) is given in Fig. 11. The resistance of the armature and series field windings is 0·08 ohm. The full-load (armature) current is 215 amperes.

This relationship between λ/γ and γ is plotted on Chart 4 (Fig. 10). Since the pressure-drop in the motor at full load is $0{\cdot}08 \times 215 = 17{\cdot}2$ volts, or $(17{\cdot}2/460)100 = 3{\cdot}75$ per cent, we must interpolate between the given curves on the chart to obtain the required

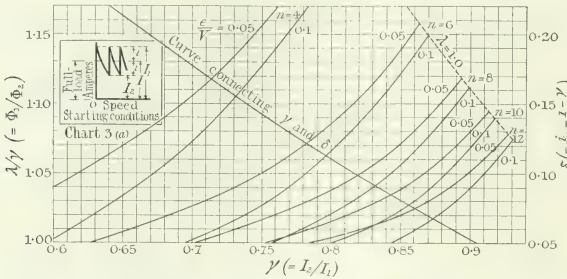

FIG. 8.—Chart for determining grading coefficients for series motor starters having 4–12 sections. Mean current during starting period equal to full-load current. Uniform current peaks.

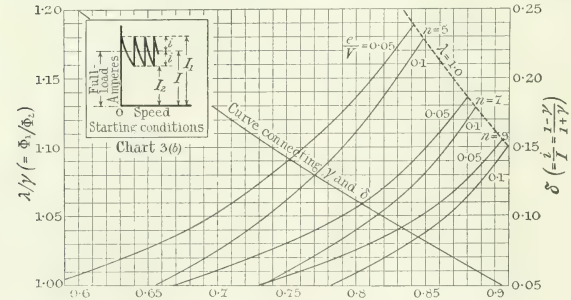

FIG. 8A.—Chart for determining grading coefficients for series motor starters having 5, 7, or 9 sections. Mean current during starting period equal to full-load current. Uniform current peaks.

As only the speed curve of the motor is available, we determine the relationship between γ and λ/γ as follows :—Select values for i (the variation of current above and below the mean starting current) at 10, 15 and 20 amperes, and calculate I_1 and I_2. For each value of I_1 and I_2 so obtained, calculate the internal E.M.F. in the armature, and obtain the speed from the speed curve. The ratio of the internal E.M.F.'s multiplied by the inverse ratio of the speeds will then give the ratio of the corresponding fluxes. The calculations are tabulated on page 877.

values for λ/γ and γ. These values are $\lambda/\gamma = 1{\cdot}03$, $\gamma = 0{\cdot}856$.

Whence $\lambda = 1{\cdot}03 \times 0{\cdot}856 = 0{\cdot}882$;
$\delta = (1-\gamma)/(1+\gamma) = 0{\cdot}077$;
$i = 0{\cdot}077 \times 215 = 16{\cdot}55$ amperes;
$I_1 = 215 + 16{\cdot}55 = 231{\cdot}5$ amperes;
$I_2 = 215 - 16{\cdot}55 = 198{\cdot}5$ amperes;
$\zeta = 231{\cdot}5/215 = 1{\cdot}0767$;
$R_1 = 460/231{\cdot}5 = 1{\cdot}99$ ohms;
and $R_1' = 460/215 = 2{\cdot}14$ ohms.

i	10		15		20	
I_1	225		230		235	
I_2		205		200		195
e_1, e_2*	18	16·4	18·4	16	18·8	15·6
E_1, E_2*	442	443·6	441·6	444	441·2	444·4
N_1, N_2*	446	455	443	457	441	460
$\lambda/\gamma(=E_1N_2/E_2N_1)$	1·017		1·027		1·036	
$\gamma(=I_2/I_1)$	0·911		0·87		0·83	

* e_1, e_2; E_1, E_2; and N_1, N_2, denote the voltage-drop, internal E.M.F., and speed, respectively, at the currents I_1, I_2.

The total resistance of the starting rheostat

$$= R'_1 - R_m = 2{\cdot}14 - 0{\cdot}08 = 2{\cdot}06 \text{ ohms}$$

The resistances of the 12 sections are calculated from Equations [15(*a*)] to [15(*n*)], thus :—

$$\begin{aligned}
R'_1 - R'_2 &= R_1\{\lambda(1-\zeta\gamma/(\gamma+(\zeta-1)\} = 1{\cdot}99 \times 0{\cdot}157 = 0{\cdot}312 \text{ ohm}\\
R'_2 - R'_3 &= \lambda(R'_1 - R'_2) = 0{\cdot}882 \times 0{\cdot}312 = 0{\cdot}275 \text{ ohm}\\
R'_3 - R'_4 &= \lambda(R'_2 - R'_3) = 0{\cdot}882 \times 0{\cdot}275 = 0{\cdot}243 \text{ ohm}\\
R'_4 - R'_5 &= \lambda(R'_3 - R'_4) = 0{\cdot}882 \times 0{\cdot}243 = 0{\cdot}214 \text{ ohm}\\
R'_5 - R'_6 &= \lambda(R'_4 - R'_5) = 0{\cdot}882 \times 0{\cdot}214 = 0{\cdot}189 \text{ ohm}\\
R'_6 - R'_7 &= \lambda(R'_5 - R'_6) = 0{\cdot}882 \times 0{\cdot}189 = 0{\cdot}167 \text{ ohm}\\
R'_7 - R'_8 &= \lambda(R'_6 - R'_7) = 0{\cdot}882 \times 0{\cdot}167 = 0{\cdot}147 \text{ ohm}\\
R'_8 - R'_9 &= \lambda(R'_7 - R'_8) = 0{\cdot}882 \times 0{\cdot}147 = 0{\cdot}130 \text{ ohm}\\
R'_9 - R'_{10} &= \lambda(R'_8 - R'_9) = 0{\cdot}882 \times 0{\cdot}130 = 0{\cdot}114 \text{ ohm}\\
R'_{10} - R'_{11} &= \lambda(R'_9 - R'_{10}) = 0{\cdot}882 \times 0{\cdot}114 = 0{\cdot}101 \text{ ohm}\\
R'_{11} - R'_{12} &= \lambda(R'_{10} - R'_{11}) = 0{\cdot}882 \times 0{\cdot}101 = 0{\cdot}089 \text{ ohm}\\
R'_{12} - R'_{13} &= \lambda(R'_{11} - R'_{12}) = 0{\cdot}882 \times 0{\cdot}089 = 0{\cdot}0785 \text{ ohm}
\end{aligned}$$

Total .. 2·0595 ohms

In Fig. 11 are shown speed/current curves corresponding to the several steps of the controller and the above starting resistance.

If the variation of flux during starting had been neglected we should have obtained the same total resistance (viz. 2·06 ohms) for the starting rheostat, but the grading of the sections would have been different. For example, γ (obtained from Equation 24) $= \sqrt[19]{0{\cdot}0375} = 0{\cdot}7605$; and the resistances of the sections (obtained by the application of Equations [19(*a*)], etc.) are :—

$$\begin{aligned}
R'_1 - R'_2 &= R'_1(1-\gamma) = 2{\cdot}14\,(1-0{\cdot}76) = 0{\cdot}5125 \text{ ohm}\\
R'_2 - R'_3 &= \gamma(R'_1 - R'_2) = 0{\cdot}76 \times 0{\cdot}5125 = 0{\cdot}39 \text{ ohm}\\
R'_3 - R'_4 &= \gamma(R'_2 - R'_3) = 0{\cdot}76 \times 0{\cdot}39 = 0{\cdot}297 \text{ ohm}\\
R'_4 - R'_5 &= \gamma(R'_3 - R'_4) = 0{\cdot}76 \times 0{\cdot}297 = 0{\cdot}2254 \text{ ohm}\\
R'_5 - R'_6 &= \gamma(R'_4 - R'_5) = 0{\cdot}76 \times 0{\cdot}2254 = 0{\cdot}1715 \text{ ohm}\\
R'_6 - R'_7 &= \gamma(R'_5 - R'_6) = 0{\cdot}76 \times 0{\cdot}1715 = 0{\cdot}1303 \text{ ohm}\\
R'_7 - R'_8 &= \gamma(R'_6 - R'_7) = 0{\cdot}76 \times 0{\cdot}1303 = 0{\cdot}0991 \text{ ohm}\\
R'_8 - R'_9 &= \gamma(R'_7 - R'_8) = 0{\cdot}76 \times 0{\cdot}0991 = 0{\cdot}0754 \text{ ohm}\\
R'_9 - R'_{10} &= \gamma(R'_8 - R'_9) = 0{\cdot}76 \times 0{\cdot}0754 = 0{\cdot}0574 \text{ ohm}\\
R'_{10} - R'_{11} &= \gamma(R'_9 - R'_{10}) = 0{\cdot}76 \times 0{\cdot}0574 = 0{\cdot}0436 \text{ ohm}\\
R'_{11} - R'_{12} &= \gamma(R'_{10} - R'_{11}) = 0{\cdot}76 \times 0{\cdot}0436 = 0{\cdot}0332 \text{ ohm}\\
R'_{12} - R'_{13} &= \gamma(R'_{11} - R'_{12}) = 0{\cdot}76 \times 0{\cdot}0332 = 0{\cdot}0253 \text{ ohm}
\end{aligned}$$

Total .. 2·061 ohms

(7) Application to Series-Parallel Control.

In the series-parallel control of traction motors the starting resistance may consist either of (i) a separate group of resistance sections for each motor, as represented in Fig. 12A; or (ii) a single group of resistance sections arranged in series with the series or parallel combinations of the motors, as represented in Fig. 12B. The former arrangement [Fig. 12A] of motors and starting rheostats is necessary when the transition from series to parallel is made by the "bridge" method. The arrangement shown in Fig. 12B is standard for tramcar controllers.

Charts 1(*a*), 2(*a*), 3(*a*) and 4(*a*) in Figs. 4, 6, 8 and 10, may be employed directly for the series notches or steps if the following points are observed.

When the starting rheostats are arranged as in Fig. 12B, the percentage pressure-drop (for the series combination of the motors) must be considered to be twice the normal value for one machine (i.e. for

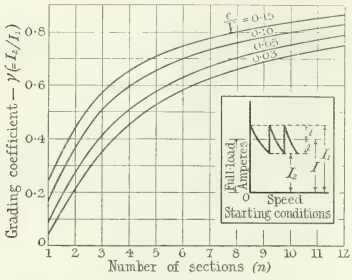

FIG. 9.—Grading coefficients for shunt motor starters. Mean current during starting period equal to full-load current. Uniform current peaks.

a motor having a 10 per cent pressure-drop at full load, the curve for a 20 per cent pressure-drop is used). This value of the pressure-drop must also be used when the starting rheostats are arranged as in Fig. 12A, but the starting resistance must be calculated for one-half of the line voltage. The values so obtained will give the starting resistance required for each motor, the two groups of rheostats being similar. The calculation of the sections of the starting rheostats for the series notches therefore presents no difficulties.

The current limits for the parallel notches usually differ from those for the series notches, although with automatic control of the notching by means of a minimum-current relay the lower limit of current will be the same for the parallel as for the series notches. Hence, if transition is effected at the lower limit of current I_2, and the current rises to the value I_1' (which is the upper limit of current in the parallel notches) then if R_{1p}, R_{2p}, etc., denote the resistances in circuit with each motor on the several parallel notches, we have, since the speed is unchanged during transition, and in passing from notch to notch,

$$\frac{\Phi_2}{\Phi_1'} = \frac{\frac{1}{2}V - I_2 R_m}{V - I_1' R_{1p}} \quad . \quad . \quad . \quad . \quad (25)$$

for the transition step, and

$$\frac{\Phi_2}{\Phi_1'} = \frac{V - I_2 R_{1p}}{V - I_1' R_{2p}} = \frac{V - I_2 R_{2p}}{V - I_1' R_{3p}} = \ldots = \frac{V - I_2 R_{np}}{V - I_1' R_m} \quad . \quad (26)$$

for the succeeding steps.

By treating these equations similarly to Equations (7),

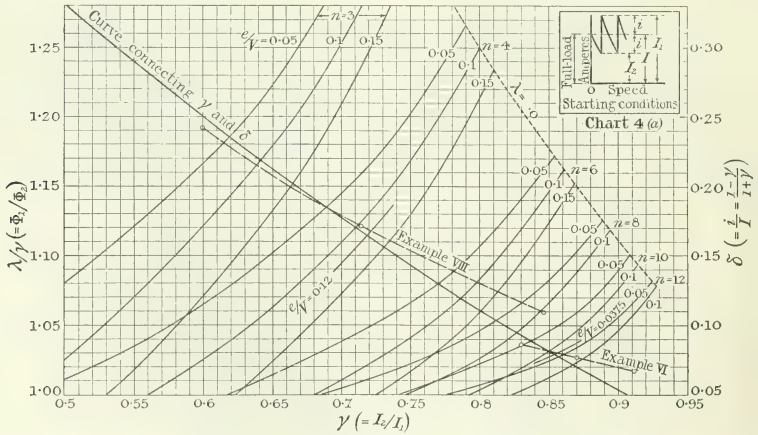

FIG. 10.—Chart for determining grading coefficients for series motor starters having 3–12 sections. Starting current and mean current during starting period both equal to full-load current.

and denoting $(\Phi_1' I_2 / \Phi_2 I_1')$ by λ_p; V/I_2 by R_0; V/I_1' by R_1''; and I_2/I_1' by γ_p we obtain

$$\begin{aligned} R_1'' - R_{1p} &= \lambda_p(\tfrac{1}{2}R_0 - R_m) \\ R_1'' - R_{2p} &= \lambda_p(R_0 - R_{1p}) \\ &\cdots\cdots\cdots \\ R_1'' - R_m &= \lambda_p(R_0 - R_{np}) \end{aligned}$$

Now $R_m = e/I$, and $R_0 = V/I_2$. Hence

$$R_m/R_0 = (e/V)(I_2/I)$$

that is

$$\frac{e}{V} \cdot \frac{I_2}{I} = \frac{(1+\alpha_p)(\gamma_p - \tfrac{1}{2}\lambda_p) - \tfrac{1}{2}\alpha_p}{(1+\alpha_p)(1-\lambda_p)} \quad . \quad (29)$$

The grading coefficients for the "parallel" sections are therefore expressed in terms similar to those for

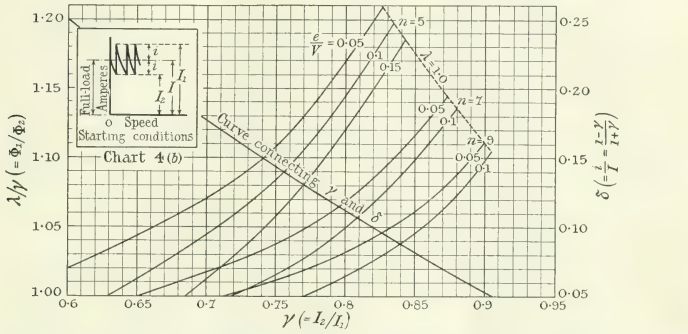

FIG. 10A.—Chart for determining grading coefficients for series motor starters having 5, 7, or 9 sections. Starting current and mean current during starting period both equal to full-load current.

Whence

$$\begin{aligned} R_{1p} &= R_1'' - \lambda_p(\tfrac{1}{2}R_0 - R_m) \\ &= R_0\gamma_p - \lambda_p(\tfrac{1}{2}R_0 - R_m) \\ &= R_0(\gamma_p - \tfrac{1}{2}\gamma_p) + \lambda_p R_m \quad . \quad . \quad . \quad . \quad . \quad (27) \end{aligned}$$

$$\begin{aligned} R_{1p} - R_{2p} &= \lambda_p\{(R_0 - R_{1p}) - (\tfrac{1}{2}R_0 - R_m)\} \\ &= \lambda_p(\tfrac{1}{2}R_0 + R_m - R_{1p}) \quad . \quad . \quad . \quad . \quad [28(a)] \end{aligned}$$

$$\begin{aligned} R_{2p} - R_{3p} &= \lambda_p\{(R_0 - R_{2p}) - (R_0 - R_{1p})\} \\ &= \lambda_p(R_{1p} - R_{2p}) \\ &= \lambda_p^2(\tfrac{1}{2}R_0 + R_m - R_{1p}) \quad . \quad . \quad . \quad . \quad [28(b)] \end{aligned}$$

$$\begin{aligned} R_{np} - R_m &= \lambda_p\{(R_0 - R_{np}) - (R_0 - R_{(n-1)p})\} \\ &= \lambda_p^n(\tfrac{1}{2}R_0 + R_m - R_{1p}) \quad . \quad . \quad . \quad . \quad [28(n)] \end{aligned}$$

Hence

$$\begin{aligned} R_{1p} - R_m &= (\tfrac{1}{2}R_0 + R_m - R_{1p})(\lambda_p + \lambda_p^2 + \ldots + \lambda_p^n) \\ &= (\tfrac{1}{2}R_0 + R_m - R_{1p})\lambda_p(1 - \lambda_p^n)/(1 - \lambda_p) \end{aligned}$$

Substituting for R_{1p} the value obtained above, and denoting $\lambda_p(1-\lambda_p^n)/(1-\lambda_p)$ by α_p, we obtain

$$\begin{aligned} &\{R_0(\gamma_p - \tfrac{1}{2}\lambda_p) + \lambda_p R_m\} - R_m \\ &\quad = \alpha_p\{\tfrac{1}{2}R_0 + R_m - [R_0(\gamma_p - \tfrac{1}{2}\lambda_p) + \lambda_p R_m]\} \end{aligned}$$

whence

$$R_0\{(\gamma_p - \tfrac{1}{2}\lambda_p)(1+\alpha_p) - \tfrac{1}{2}\alpha_p\} = R_m(1+\alpha_p)(1-\lambda_p)$$

and

$$\frac{R_m}{R_0} = \frac{(1+\alpha_p)(\gamma_p - \tfrac{1}{2}\lambda_p) - \tfrac{1}{2}\alpha_p}{(1+\alpha_p)(1-\lambda_p)}$$

the "series" sections. Observe that we have the ratio of the *lower* limit of current to the full-load current,

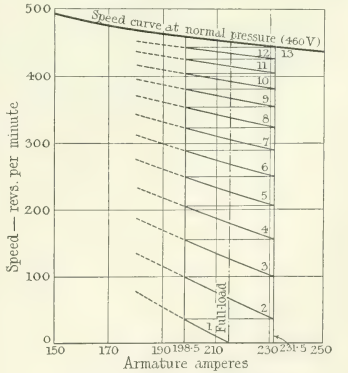

FIG. 11.—Speed curves for 120-h.p. compound motor and 13-point controller (calculated in Section 6).

since this lower limit is known, being the same for both parallel and series notches.

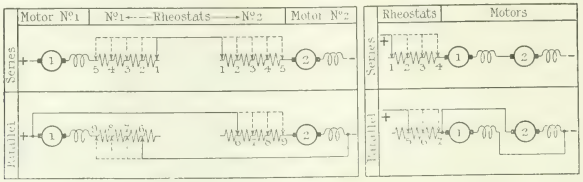

FIG. 12A. FIG. 12B.

Diagrams showing combinations of motors and rheostats for series-parallel control.

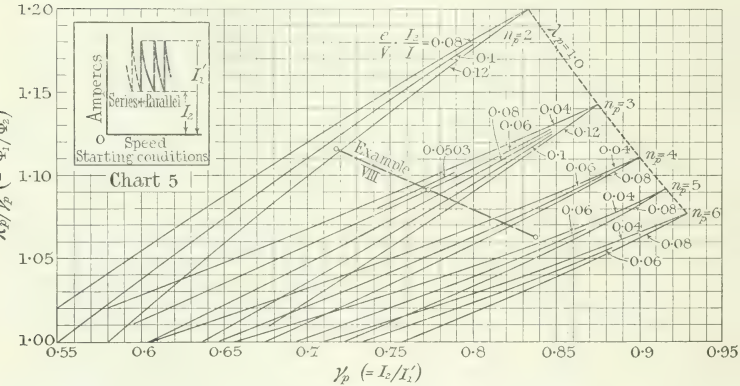

FIG. 13.—Chart for determining grading coefficients for parallel steps of series-parallel controllers for series motors.

i	25		50		75	
I_1	325		350		375	
I_2		275		250		225
e_1, e_2*	39	33	42	30	45	27
E_1, E_2*	561	567	558	570	555	573
N_1, N_2*	18·4	19·7	17·9	20·5	17·45	21·5
λ/γ ($= E_1N_2/E_2N_1$)	1·059		1·121		1·192	
γ ($= I_2/I_1$)	0·846		0·714		0·6	

* e_1, e_2; E_1, E_2; and N_1, N_2 denote the voltage-drop, internal E.M.F., and speed, respectively, at the currents I_1, I_2. The speeds are given in miles per hour.

Chart 5 calculated from Equation (29) is given in Fig. 13. This chart is used for obtaining the grading coefficients for the "parallel" sections of the rheostats in the same way as the previous charts.

(8) Example. Calculation of Starting Resistance for Two 225-h.p., 600-volt Railway Motors and Series-parallel Control. Bridge Transition.

This example will be calculated for a series-parallel controller, having five series and four parallel notches, in which separate resistances are used for each motor in both the series and parallel positions (Fig. 12A).

The current corresponding to the rated load of 225 h.p. at 600 volts is 320 amperes. The mean starting current for the series notches is to be 300 amperes, the initial current is to be limited to this value, and the lower limit of current is to be the same for both series and parallel positions. The resistance of each motor is 0·12 ohm. A speed curve for normal voltage (600 volts) is given in Fig. 14 (curve A).

The relationship between λ/γ and γ is obtained from this curve in a manner similar to that adopted in Section 6, but in this case we select values for i at 25, 50 and 75 amperes. The calculations are tabulated on page 880, and the relationship between λ/γ and γ is plotted on Chart 4(*a*) (see Fig. 10).

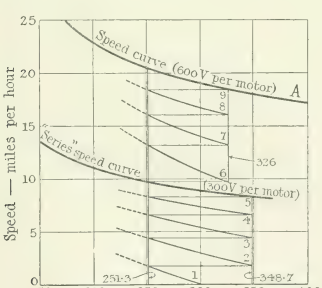

Fig. 14.—Speed curves for 225-h.p. railway motors and series-parallel controller (calculated in Section 8).

For the series notches we calculate the starting resistance (per motor) for a 300-volt supply circuit. The pressure-drop in the motor at 300 amperes is $300 \times 0{\cdot}12 = 36$ volts, which is $(36/300)\ 100 = 12$ per cent of the "series" terminal pressure. Hence we must interpolate between the 10 per cent and 15 per cent curves on Chart 4(*a*) (Fig. 10) to obtain the required values of λ/γ and γ. These values are $\lambda/\gamma = 1{\cdot}117$, and $\gamma = 0{\cdot}721$.

We therefore obtain

$$\lambda = 1{\cdot}117 \times 0{\cdot}721 = 0{\cdot}806;$$
$$\delta = (1 - \gamma)/(1 + \gamma) = 0{\cdot}162;$$
$$i = 0{\cdot}162 \times 300 = 48{\cdot}7 \text{ amperes};$$
$$I_1 = 300 + 48{\cdot}7 = 348{\cdot}7 \text{ amperes};$$
$$I_2 = 300 - 48{\cdot}7 = 251{\cdot}3 \text{ amperes};$$
$$\zeta = 348{\cdot}7/300 = 1{\cdot}162;$$
$$R_1 = 300/348{\cdot}7 = 0{\cdot}861 \text{ ohm};$$
and $$R_1' = 300/300 = 1 \text{ ohm}.$$

The resistance of the starting rheostat $= (R_1' - R_m)$ $= 1 - 0{\cdot}12 = 0{\cdot}88$ ohm.

The resistances of the four sections are calculated from Equations [15(*a*)] to [15(*n*)], thus :—

$$R_1' - R_2' = R_1\{\lambda(1 - \zeta\gamma)/\gamma + (\zeta - 1)\} = 0{\cdot}861 \times 0{\cdot}343 = 0{\cdot}2955 \text{ ohm}$$
$$R_2' - R_3' = \lambda(R_1' - R_2') = 0{\cdot}806 \times 0{\cdot}2955 = 0{\cdot}238 \text{ ohm}$$
$$R_3' - R_4' = \lambda(R_2' - R_3') = 0{\cdot}806 \times 0{\cdot}238 = 0{\cdot}192 \text{ ohm}$$
$$R_4' - R_5' = \lambda(R_3' - R_4') = 0{\cdot}806 \times 0{\cdot}192 = 0{\cdot}1545 \text{ ohm}$$
$$\text{Total} \quad .. \quad 0{\cdot}88 \text{ ohm}$$

For the parallel notches we have

$$I_2 = 251{\cdot}3 \text{ amperes};$$
$$I_2/I = 251{\cdot}3/300 = 0{\cdot}838;$$
and $$(e/V)(I_2/I) = (36/600) \times 0{\cdot}838 = 0{\cdot}0503.$$

The relationship between λ_p/γ_p and γ_p is obtained as follows :—

The lower limit of current I_2 for the parallel notches being known, values are assumed for the upper limit I_1', and the ratio of the fluxes corresponding to these current ratios is calculated, thus giving λ_p/γ_p. The calculations are set out in tabular form on page 882.

This relationship is plotted on Chart 5 (Fig. 13), and the intersection with the interpolated curve for $(e/V)(I_2/I) = 0{\cdot}0503$ and $n = 3$ gives $\lambda_p/\gamma_p = 1{\cdot}093$; $\gamma_p = 0{\cdot}77$. Therefore

$$\lambda = 1{\cdot}093 \times 0{\cdot}77 = 0{\cdot}842;$$
$$I_1' = 251{\cdot}3/0{\cdot}77 = 326 \text{ amperes};$$
and $$R_0 = V/I_2 = 600/251{\cdot}3 = 2{\cdot}39 \text{ ohms}.$$

The total external resistance required for each motor in the first parallel combination is obtained from Equation (27) thus :—

$$R_{1p} = R_m = R_0(\gamma_p - \tfrac{1}{2}\lambda_p) - R_m(1 - \lambda_p)$$
$$= 2{\cdot}39(0{\cdot}77 - \tfrac{1}{2} \times 0{\cdot}842)$$
$$- 0{\cdot}12\,(1 - 0{\cdot}842) = 0{\cdot}815 \text{ ohm}$$

Hence $$R_{1p} = 0{\cdot}815 + 0{\cdot}12 = 0{\cdot}935 \text{ ohm}$$

I_2		251·3			251·3			251·3	
I_1' (assumed)	300			325			350		
e_1, e_2	36		30	39		30	42		30
E_1', E_2	564		570	561		570	558		570
N_1', N_2	19		20·4	18·4		20·4	17·9		20·4
$\lambda_p/\gamma_p (= \Phi_1'/\Phi_2 = E_1'N_2/E_2N_1')$		1·063			1·092			1·116	
$\gamma_p (= I_2/I_1')$		0·838			0·773			0·718	

The resistances of the three sections are obtained by applying Equations [28(*a*)] to [28(*n*)], thus :—

$$\begin{aligned} R_{1p} - R_{2p} &= \lambda_p(\tfrac{1}{2}R_0 + R_m - R_{1p}) = 0{\cdot}842(\tfrac{1}{2} \times 2{\cdot}39 + 0{\cdot}12 - 0{\cdot}935) = 0{\cdot}32 \text{ ohm} \\ R_{2p} - R_{3p} &= \lambda_p(R_{1p} - R_{2p}) = 0{\cdot}842 \times 0{\cdot}32 = 0{\cdot}269 \text{ ohm} \\ R_{3p} - R_{4p} &= \lambda_p(R_{2p} - R_{3p}) = 0{\cdot}842 \times 0{\cdot}269 = 0{\cdot}226 \text{ ohm} \\ & \qquad\qquad \text{Total } .. \quad .. \quad 0{\cdot}815 \text{ ohm} \end{aligned}$$

Speed/current curves corresponding to normal supply pressure (600 volts) and the several steps of the controller and the above starting resistance are given in Fig. 14.

Note.—In practice it would be necessary, for the purpose of reducing the number of contactors in the control equipment, to use certain sections of the starting rheostat for both series and parallel combinations of the motors. In the present case a compromise would be necessary to effect this result.

DISCUSSION ON

"ELECTRIC MOTOR STARTERS."*

Western Centre, at Cardiff, 1 May, 1922.

Major R. Amberton: The author emphasizes the desirability of full information as regards the load and starting torque with which a given starter will have to deal. I agree that not only is this desirable, but that it is essential in many cases. It frequently happens, however, that the user is unable to furnish the information and, again, may wish to use the same starter on more than one job. Mechanical considerations are a large factor in the design of motor starters, and the size of a given starter is frequently governed by the space taken by the resistance. This is nearly always greater than the actual space required for the starter front, and the front itself frequently has room for more steps then are actually required, so that the question of saving a step or two through exact knowledge of starting conditions is not, in my opinion, an important factor—at any rate as regards the smaller sizes, and particularly when the greater adaptability of the starter with an ample resistance and ample number of steps is taken into account. From the commercial point of view, the principal objections to the strictly "made to measure" starter are: (1) The makers cannot standardize; (2) the user has to pay more for special apparatus; and (3) the user may not be able to use the starter on another job—or on the same one under varied conditions. The author mentions the necessity for the quick breaking of the arc. This is of course essential when breaking direct currents, but is a distinct disadvantage when breaking alternating currents, where a slow break has been found to be very much more satisfactory. I am also not quite in agreement with the author's contention that a starter should be used for accelerating only, and should never be called upon to break the circuit. It is a growing practice to embody a contactor in the design of a starter, and the function of this contactor is to make and break the circuit. In most adaptations there is a "dead man's handle" effect, to ensure that, whilst the resistance can be cut out with the starter handle, the circuit is always broken by the contactor before any rearward movement of the starter arm can be effected. It may be argued that the contactor is not part of the starter but, inasmuch as the starter would

* Paper by Mr. J. Anderson (see page 619).

not function without the contactor, I think the two must be regarded as one entity.

Mr. H. S. Ellis: It is very true that most people do not take a great deal of trouble in specifying details in connection with starters, and the conditions under which they are to be used, but it is undoubtedly an important subject, and one to which we shall have to devote a great deal more time in the future. I have in mind the case of a 15-h.p. slip-ring motor coupled to a spindle borer set, which was set to work about the middle of last year. This motor ran quite satisfactorily until one cold morning in October when the starter burnt out. The whole of that trouble was due to the effect of the cold on the grease used for lubricating the spindle bearings which, on a Monday morning, was very thick. Although the makers of the spindle borer were approached, they were quite unable to help us as to the correct starting current to allow for on this particular machine. The difficulty was soon got over by using a different class of grease and a different section of wire on the rotor resistance. There are, of course, exceptional cases, and I have in mind the case of another motor at the same works coupled to a punching and shearing machine which, as usual, is fitted with a very heavy flywheel. Knowing that the inertia to be overcome was very great, it was arranged that this motor, which was of the squirrel-cage type, should drive on to a fast and a loose pulley, but for some reason the necessary pulleys were not produced in time. As he was most anxious to get the machine to work, the manager insisted on belting the motor direct on to the flywheel of the machine, naturally very much against our wishes. However, although we advised that this arrangement should not be continued, the machine is still running satisfactorily. This is obviously a case where either the motor should have been coupled up in accordance with our original intention or a special type of starter used. Naturally, the acceleration is very great because within a few seconds of closing the switch the machine is up to its full speed. With regard to the author's remarks about the temperature of starter elements immersed in oil, I should like to ask him whether any starters of this type are arranged so that the oil is agitated at the time of starting up the motor. I feel that if this were done the heat from the elements would be dissipated more rapidly.

Major E. I. David: This paper, with its facts concerning arc formation at contacts and difficulties in suitably grading resistances to suit various conditions of load, confirms my opinion that for colliery and heavy industrial work the liquid starter is preferable. The photographs of arcs are also particularly interesting and confirm some observations and photographs taken of arcs produced on air-break contactors dealing with the no-load current of a 1 600-h.p. winding motor. These arcs had shapes very similar to those shown in the photographs. The author remarks that in the case of winders the motor acceleration is not of great importance. This is true of direct-coupled low-speed motors, where the inertia of the motor rotor is small compared with that of the drum and other moving masses, but in the case of geared winders the rotor inertia is a large proportion of the total inertia, and is one of the deciding features in fixing the speed of the motor. The author refers to contactor-type starters as suitable for haulages or even winders. Some 11 years ago I installed such a starter on a large haulage dealing with peaks up to 1 000 h.p. This has run satisfactorily as far as the actual rotor control is concerned, but a considerable amount of trouble has been experienced with the stator contacts, which operate at 3 000 volts. I have recently installed another contactor-type controller on a slightly smaller haulage. This is a more modern pattern and has given no trouble either in the stator or rotor circuits. The current variation during acceleration is very considerable. In view of the very heavy acceleration necessary in colliery winders, in some cases as high as 6 to 7 feet per second, the contactor-type or any other step-by-step starter is not suitable, as the slightest variation in the motor torque sets up oscillations in the rope, which oscillations may become dangerous. In addition, in geared winders chattering and backlash in the gears is produced. The figures showing that unbalanced resistances in the phases of the rotor have very little effect on the resultant torque are interesting, as in some large weir-type liquid controllers in operation on winders it was noticed that during the acceleration period the liquid foamed up between the plates, in some cases 1 ft. above the normal level of the liquid, with resulting serious unbalanced resistance in the phases. This foaming was accompanied by violent sparking on the surface of the liquid, but it was noticed that there was practically no variation in the stator current due to these short-circuits, and the torque of the motor appeared to be uniform. An important point in connection with winders is the torque obtained with various rotor resistances under reversed current. The general impression is that the greater the resistance in circuit, the lower will be the resulting torque, but this is not correct, as there is a definite resistance which will give the maximum torque for every speed, either positive or negative. For the 1 600-h.p. motor previously referred to it was found that 1/16th of the maximum resistance which the controller could insert gave $2\frac{1}{2}$ times full-load torque at zero speed and at 100 per cent negative speed; 1/8th of the maximum resistance gave $1\frac{3}{4}$ times full-load torque at zero speed and $2\frac{1}{2}$ times full-load torque at 100 per cent negative speed; and one-quarter of the maximum resistance gave less than full-load torque at zero speed and $1\frac{1}{2}$ times full-load torque at 100 per cent negative speed. With the controller resistance all out as far as possible, with maximum electrolyte resistance, $\frac{1}{4}$ full-load torque could be obtained at zero speed, and $\frac{1}{2}$ full-load torque at 100 per cent negative slip, but under these conditions the slip at full-load torque with all possible resistance cut out was approximately 5 per cent, i.e. higher than desirable. The strength of the electrolyte was therefore increased, halving the resistance, and it was found that ample control was still provided and the slip was reduced to $2\frac{1}{2}$ per cent. The controller in this instance was of the moving-electrode type. Auto-starters for mining use have been a great source of trouble.

The men who operate these starters are firmly convinced that there is only one position for a switch, and, as an auto-starter looks like a switch, this is included in the switch category. If the starting handle will not stay in the first position reached, then it is made to stay there by fixing it either by a piece of wood or some wire or string. As a result the compensator coils are burned out and the whole machine goes out of commission. For squirrel-cage motors up to 20 h.p. I am strongly in favour of switching straight on to the line. For horse-powers above this Y-delta starters are usually most satisfactory.

Mr. C. G. M. New: I am inclined to agree with Major David that there is some virtue in a liquid starter for some conditions and duties. It has a flexibility which at times is very useful and I have experience of one in connection with a 500-kW induction motor-generator set, where the starting conditions have been known to alter after the set has been down for overhaul. The author has made no reference to single-phase starters, and in his criticism of the lack of information given by motor manufacturers to starter makers I presume that, where single-phase motors are concerned, manufacturers must of necessity give more information in order to obtain a satisfactory starter. I was particularly interested in the tables showing the effect of different taps on auto-transformer starters, and I feel that the information given is of practical value. With regard to the air-break circuit breakers, I gathered from the author's remarks that the width of the arc did not vary in the tests carried out. I should like to know whether draughts would have any effect on this point with breakers not fitted with magnetic blow-outs, as I have experienced considerable trouble on one switchboard controlling traction supplies, due to arcing to metal work some distance away.

Mr. T. Hood: I feel that the author has served an excellent purpose in bringing this subject forward, because I think that, to a large extent, the majority of us who have not had specific experience in the manufacture of starting gear have been somewhat careless in purchasing. We have inquired for a starter of a certain size based on the horse-power of the motor rather than on the conditions under which the motor would have to work. It is obvious that if the B.E.S.A. can publish a standard specification for starters, consulting engineers generally will be able to define more clearly the requirements with which the starter must comply. The author has not made any special reference to the material of which resistance elements are made. The majority of starter makers appear to have their own particular views on this subject. Some years ago a manufacturer endeavoured to make up standard composition resistance units in bobbin form. These were not successful either technically or commercially, but many manufacturers to-day claim that their alloys are unbreakable and rustless. Another type of starter to which the author has made no reference is the compression starter made some time ago by Messrs. Ferranti, Ltd. I have found the liquid starters of which Major David speaks so highly to be very troublesome due to the creeping of soda-laden water over the contacts, and the fact that the ohmic value of the electrolyte is so much altered by the heating effect. Another matter to which Major David alluded was his preference for starting up squirrel-cage motors by switching them straight into the line without any resistance whatever. I fear that if this practice were to be carried out on public supply mains, there would be a possibility of the current being cut off. It has often occurred to me that the possibilities of mechanically operated, automatic cut-out gear for squirrel-cage motors have not been sufficiently investigated. The type of gear to which I refer is the centrifugal type employed quite successfully on the repulsion-induction type of radial commutator motor manufactured by such firms as the Century Electric Co., Ltd., of America. Whilst on this question of starting up squirrel-cage motors, or motors with like starting characteristics, that are frequently started and stopped, I think that the question of the watts absorbed at starting by squirrel-cage motors or motors with similar starting characteristics has not been sufficiently investigated. It is obvious that a considerable waste of energy can be brought about by an inefficient starter, and the cost of this wasted energy would show annually a very large percentage on the difference in cost between a properly graded starter and one improperly graded. The author refers to the great importance in securing accurate data in respect to resistance units, and to the fact that they should be shielded from draughts. He does not quote any figures, but I presume that the ohmic value of any resistance unit is directly affected by its temperature. If that is so, it would seem to point to the fact that artificial cooling by fans might be employed for larger resistance units. It is now quite common to incorporate fans in armature and rotor construction of motors to reduce temperatures, and I should like to know if the author considers this proposition to be practicable for resistances. The temperature of the air has a very material effect upon starting conditions. I witnessed some tests on a Hoe printing press some years ago, and it was found that on starting up after standing for 24 hours it absorbed about 50 h.p., whereas for everyday running the starting effort was only about 25/30 h.p. In such a case it would be very advantageous if the resistance elements could be promptly and easily varied at will.

Mr. Ll. Hughes: My experience has been that starter manufacturers are not prepared to depart from their standard types to meet the requirements of the user. I have in mind a 300-h.p., three-phase induction motor on an underground haulage. This motor is controlled on what is known as the Patchell system. The rotor is wound two-phase and works in a three-phase stator. It was necessary to change this control for a modern equipment, and a liquid control was preferred. Some of our best English starter makers were approached. Two firms quoted for a three-phase starter and the other said it was impossible to design a liquid starter for a two-phase rotor to be satisfactory. They recommended rewinding the rotor three-phase. This haulage kept one half of the colliery going, and to stop this haulage for rewinding the rotor would mean a serious loss. Some time ago a representative

of the German firm that supplied this motor offered to furnish the required starter. I should like the author's opinion on this matter. What are the difficulties in the way of the design of a suitable liquid starter for such conditions? I think that starter makers should be prepared to leave their standard types and meet any unusual circumstances with which the user has sometimes to contend. Again, the electrical engineer does not always possess the necessary portable instruments to test for the information required by the starter manufacturers. Another point brought up in the discussion was the creeping that occurs with liquid starters. My experience is that starters of the open type with iron tanks are the worst in this respect, and that the totally enclosed type with earthenware cylinders and piston electrodes are the best.

Mr. J. W. Fidoe: The tendency in most branches of heavy electrical engineering, and particularly in mining, is to install ironclad starters and switchgear of a mechanical design which provides a large margin to cover unforeseen stresses arising either from electrical disturbances or mishandling on the part of the operator. The author's remark that makers are frequently not given sufficient detail of the circuit conditions is no doubt true to a certain extent. On the other hand, it frequently happens that owing to the variable character of the load and the uncertain time-factor of the period of motor acceleration it is not possible to give more than a general indication. A mine haulage motor is one of the most difficult machines as far as control is concerned; usually a sufficient margin is provided by allowing for starting with twice full-load torque four times per hour, with an acceleration period of about 15 seconds. The circumstances change so rapidly, however, following on an alteration of gradient in the coal seam or of the tonnage to be dealt with, that the gear may be called upon to deal with either an increase of individual loads or a greater number of loads per hour. This variation in the cycle of operation is not conducive to the close specification of motor starters, and consequently the liquid starter has come generally into favour on large installations where the conditions are uncertain. It is not suggested that the liquid resistance is an ideal form of apparatus, but it has the advantage of being relatively cheap and comparatively robust, the chief trouble being due to occasional creepage, and in certain cases difficulties arise where the cooling water is limited in quantity. The drum-type controller is being discarded for large motors owing to trouble with the burning of contacts and, where the liquid starter is not suitable, contactor gear is now being used as an alternative.

Mr. J. B. G. Lewis: It would be of special interest to those engaged in mining work if the author would give some information, first, as to the head of oil above the fixed and moving contacts which should be obtained in a well-designed mining type oil switch, and secondly, as to what effect is caused by bubbles being constantly set free to rise to the surface of the oil. I should also like to know what, in the author's opinion, is the best way of preventing an abnormal rush of bubbles after the switch has been operated, and whether it is yet possible to render ineffective the collection of gas above the surface of the oil.

Mr. C. T. Allan: Has the author any information as to the mechanical effect on isolating switches of excessively heavy short-circuit currents?

Mr. A. C. MacWhirter: The manufacturer and designer could learn much to their advantage by ascertaining from the engineer who has to care for them in operation what faults he has found in the design and under what conditions the gear has to work. There are two distinct groups of starters. One is an engineering production which combines skill in design and reliability in service. The other is cheap, but is very necessary to compete with the imported article. I should like to know if anything has been done with the semi-solid graphite form of starter.

Mr. J. Anderson (*in reply*): Major Amberton states that the user is frequently unable to furnish the data required by the starter designer, and this is true if he is required to give the data in electrical terms; for that reason all existing and proposed standard specifications are useless. On the other hand, the user can always give the mechanical data; he can always state the size and type of machine the motor is to drive, and by means of tables, such as Nos. 1 and 2 in the paper, the designer can readily select a standard size of starter suitable for the duty. If required, he can supply the user with a table of equivalent torques, stored energy and time, thus facilitating the intelligent use of the starter on various jobs. The provision of an extra step or two increases the price very considerably when it is necessary to pass from one standard size to the next larger to get them, and this expense may frequently be avoided when exact data are available.

Major Amberton rather misses the point in his remarks on the "made-to-measure" starter. In practice, the designer decides on certain sizes which give a reasonable difference of price from size to size, and designs the resistance space for the duty of most frequent occurrence, e.g. a duty similar to shop shafting with 60 per cent running torque during the accelerating period, 1 000 ft.-lb. per brake horse-power stored energy, and 30 seconds accelerating time. When he gets the exact mechanical data of any particular job he selects from his standard range the size which is suitable, and it is only when the price consideration is sufficient that he makes up a special starter by combining the dial of one size with the resistance of another. The user can apply that starter to any other job within its capacity, and he has the satisfaction of knowing that he has got the right starter for his job at the right price. A starter fitted with a contactor operating at the first backward movement of the handle fulfils the requirement that interruption of the circuit should be done by a breaker if the sparking tip of the contactor is accessible and renewable at low cost, and if its breaking capacity is sufficient. A contactor merely breaking at the first notch does not meet the case, because from 30 to 50 per cent of the total energy dissipated by the starter is dissipated between notches 1 and 2.

As regards the low-speed breaker for a.c. circuits, a recent test on a welding plant gave $\frac{1}{16}$ in. slow break

in oil for 600 amperes, 440 volts and 25 periods. A test in air gave a separation of 0·014 in. slow break between copper electrodes $\frac{1}{2}$ in. diameter for 120 amperes, 440 volts and 25 periods, while a quick-break switch drew out an arc $1\frac{1}{2}$ in. long. In general, a quick break is necessary only over a limited distance, and the breaking capacity does not necessarily depend on a long, quick break.

In reply to Mr. Ellis, agitation of the oil is effective in distributing the heat through the whole mass, and for onerous duties paddles are sometimes fitted on oil starters for this purpose. The utility of agitation of the oil in circuit breakers depends on the direction of motion given to the oil. If it is upwards, tending to bring the arc to the oil surface, it is bad; if it is directed to keep the arc below the oil surface it is advantageous.

Major David states that he prefers liquid starters for a number of reasons, one being that the resistance of the electrolyte can be altered readily to suit starting conditions. This facility has the disadvantage of its merits, in that any unauthorized person can alter the resistance, with resulting damage to the motor or disturbance of the supply, and low level can be readily rectified by the attendant after the trouble, thus removing the evidence of the cause. Undoubtedly there are circumstances in which none but liquid starters should be used, but for accurate work it is necessary to use resistances having a negligible temperature coefficient. It is noteworthy that nearly every advocate of liquid starters has to refer to troubles from foaming, arcing or leaking.

As regards auto-transformers versus star-delta starters, I agree that the latter are preferable for rough work and that there are many conditions where it is preferable to throw the motor direct on to the line, especially if the supply is from a private plant; the supply authorities and the insurance companies generally object to this.

The data given by Major David regarding the torques with reversed current are interesting in connection with crane control where the load can drive the motor.

In reply to Mr. New, single-phase motor makers frequently prefer to adjust the resistances themselves, presumably because the initial starting torques are low and it is very difficult to get exact data. The size of the arcs from air-break circuit breakers increases with the current and voltage, and decreases with the magnetic field. Draught, of course, affects the arc, but the arc reaching metal work at a distance is possibly only partially due to this cause. Everyone familiar with power supply knows of cases where arcs have jumped incredible distances in air, and the effect is probably due to ionization rendering the air conductive.

I agree with Mr. Hood that if standard specifications were to mention materials and suitable temperature-rises they would be very useful, but if they attempted to go further they would be ignored because the possible starting conditions are infinite.

Compression starters were not mentioned in the paper because they are not in general use, although they have been made by several firms for many years. The difficulties with such starters consist in getting the resistances right and in the impossibility of compressing to zero resistance, and a considerable current-rush frequently occurs when short-circuiting the resistance.

Centrifugal starters appear to be very attractive at first sight, but they have been tried and abandoned by several firms. The resistance has to be cut out in a geometric ratio, and it is difficult to obtain this with the motion obtained by centrifugal action.

Fans have frequently been considered for lowering the temperature of resistances. They might be very useful in large jobs which received adequate attention, but starters, controllers and resistances are even more neglected in service than switchgear, and if a fan did not start the resistance would burn out. The fans generally would be of small size and it is feared that they would cause a good deal of trouble.

In reply to Mr. Hughes, I do not know of any difficulty in supplying a rotor starter for a three-phase motor with a two-phase rotor.

The effect of an increased head of oil mentioned by Mr. Lewis is to decrease the temperature-rise. In oil breakers the head of oil is of first importance, and is in many cases more important than the length and speed of break, and might be taken to determine the breaking capacity; it certainly determines its capacity as regards the risk of igniting an explosive gaseous mixture in the space above the oil.

In reply to Mr. Allan, electromagnetic effects in starters are in general too small to cause trouble, but on large supply stations trouble has been experienced due to isolating plugs and switches opening. An instance occurred a short time ago, in which a transformer in a substation was protected by an automatic breaker and an oil-immersed non-automatic isolating switch. The automatic breaker opened on a short-circuit; the non-automatic breaker was found to be closed but with the oil tank bulged and the contacts marked, showing that the brushes had separated from the fixed contact blocks.

Semi-solid forms of starter of the type mentioned by Mr. MacWhirter have been tried, but there are practical difficulties in getting the correct resistance, and makers generally have standardized on resistance alloys as being the most convenient.

MECHANICAL AND ELECTRICAL EFFECTS OF LARGE CURRENTS ON HIGH-TENSION SWITCHGEAR.

By C. C. Garrard, Ph.D., Member.

(Notes in connection with an exhibition of cinematograph films at The Institution *12th January, before the* Liverpool Sub-Centre *16th January, before the* North Midland Centre *28th February, before the* Tees-side Sub-Centre *2nd March, before the* North-Western Centre *10th March, and before the* South Midland Centre *5th April,* 1922.)

The tests described in these notes were carried out by the New York Edison Company and were recorded in a paper * by Mr. Philip Torchio.

In a recent conversation with Mr. Torchio I suggested that British engineers would appreciate the opportunity of seeing the films illustrating the experiments, and he has been good enough to send them for exhibition this evening.

Oil Switch Tests.

The experiments with switches were made with currents of the order of 100 000 amperes, 25 periods, but at low pressures (about 200 volts). The object of the tests was not to determine the breaking capacity of the switches, but to find out in what way the apparatus withstood the very large mechanical stresses set up by these very large currents. In all the switch tests, the circuit breakers were mechanically locked in the closed position. The arcing seen in the films is due to the opening of the main and of the arcing contacts caused by the mechanical force resulting from the high current. The justification for such a test lies in the fact that the short-circuit current in actual practice in a power station reaches its maximum value with great rapidity and before the operating mechanism has had time to open. During the period before the automatic opening of an oil circuit breaker, at which time it is, in effect, locked in the closed position, its mechanism must withstand the mechanical forces set up by the current which may, moreover, be greater than that corresponding to its kVA breaking capacity. If, for example, the circuit breaker be chosen under the assumption that the short-circuit current falls off to 6/10ths of its maximum value within $\frac{1}{4}$ second, the mechanical forces set up before the breaker operates will be those due to a current 66 per cent greater than that corresponding to the kVA rating of the circuit breaker.

It must not be assumed from the film that the switches which apparently fail were in all cases inadequate to withstand a test equal to their rating. The numerical figures of the tests must be studied in order to arrive at a conclusion in this respect, as in some cases the testing currents were increased above those corresponding to the breaking capacity rating in order to compare different types of construction.

Influence of the Shape of the Electric Circuit.

It was found that practically all the circuit breakers tested had brush contacts arranged as in Fig. 1, so that when the current flowed the resultant mechanical force acted in a direction opposed to the brush pressure, thus tending to open the contacts and cause them to burn and weld together. This can be understood by reference to the principle that a closed electric circuit always tends to open out and enclose the maximum area.

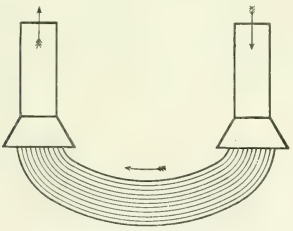

Fig. 1.—Brush which tends to come out of contact under the influence of current.

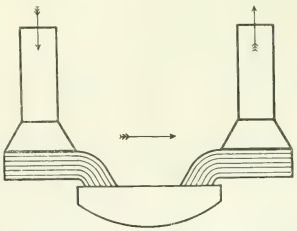

Fig. 2.—Improved inverted brushes which tend to press on tighter due to magnetic forces set up by the current.

As a result of the experiments an improved arrangement of the brushes was introduced and is illustrated in Fig. 2, from which it will be seen that the force set up by the current *increases* the brush pressure. The film clearly shows the improvement that is effected. Some of the best results, however, were obtained with finger contacts as in Fig. 3 (A), from which it will be seen that in such contacts the current flows through each finger in the same direction. The fingers, therefore, attract each other under the influence of

* *Journal of the American Institute of Electrical Engineers*, 1921, vol. 40, p. 120.

the current, and thus the contact pressure is increased. Fig. 3 (B) has been introduced by me to illustrate a construction whereby this attracting force may be increased by bringing the fingers very near together.

Tests on Current Transformers

The results clearly show the large forces to which current transformers are subjected on short-circuit. In one test (original Fig. 18) the transformer was destroyed in half a second at 92 000 amperes (R.M.S.).

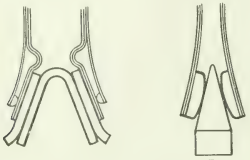

Fig. 3.—Finger contacts of oil circuit breakers. The current flowing in the same direction in both fingers causes them to attract each other and increase the contact pressure.

Mr. Torchio's conclusion is that only the single-turn primary type is suitable for large systems. I should like to point out, however, that it is not always possible to use this type in feeder circuits.

Tests on Potential Transformer Fuses.

These tests were carried out at the full pressure of 6 600 and 13 000 volts. The definite conclusion arrived at was that no type of potential fuse on the market can satisfactorily open a short circuit without the addition of a resistance (see Fig. 4). As an example it may be mentioned that a fibre-tube fuse having a resistance of 79 ohms failed completely at 6 600 volts, the current being 1 970 amperes (maximum). The addition of 50 ohms external resistance reduced the current to 25 amperes (maximum), when the fuse operated without visible disturbance in 0·02 of a period.

Tests on Disconnecting Switches.

The need of locking devices and the desirability of avoiding bends in the leads to the switches was

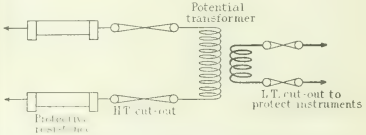

Fig. 4.—Potential transformer with protective resistance. Suggested British standard arrangement for heavy systems.

demonstrated, but when these cannot be avoided the blade opening should be at right angles to the main lead.

Conclusion.

The original paper shows the valuable information which can be obtained by collaboration between manufacturers and supply authorities. Such co-operation under the direction of the British Electrical and Allied Industries Research Association will doubtless yield similar results in this country.

Discussion before the North Midland Centre, at Leeds, 28 February, 1922.

Mr. R. D. Spurr: The experiments shown on these films are doubly interesting as they represent types of switches in common use in this country, and, although the tests resulted in the almost complete destruction of the switches, we must not forget that we are to-day operating switches that may be called upon at any moment to operate under very similar conditions for the first few periods when a fault occurs. Owing to the necessity of a public supply undertaking having to take immediate steps to resume the supply when an interruption occurs, it often happens that time and circumstances will not always permit the damaged apparatus to be thoroughly examined by engineers who can visualize what has occurred and record their observations for future use. A switch of very similar design to Fig. 1 in Dr. Garrard's "Notes" failed to open on a heavy cable fault where three feeders were operating in parallel. At the generating station the faulty feeder switch opened quite satisfactorily; at the substation, however, the two sound feeder switches opened and cleared the fault but also interrupted the supply to the substation. Upon an inspection being made of the defective switch it was found that one of the auxiliary sparking fingers had been welded to the bottom block sufficiently long to prevent the switch opening when the reverse relays came into action. These relays were supposed to be able to operate instantaneously, but evidently the time-lag was sufficiently long to allow the switch to "freeze in." This experience leads us to conclude that this particular type of switch must no longer be used on systems of any magnitude in places where "fault" or "short-circuit" conditions can bring about these heavy currents. As the type of switch illustrated in Fig. 3(A) has been found to be much more satisfactory we can in many cases substitute the latter type for the former without extensive alterations to the cubicle structure, and at the same time considerably relieve the minds of those responsible for the operation of the plant.

THE EFFICIENCY OF OVERLAPPING JOINTS IN COPPER AND ALUMINIUM BUSBAR CONDUCTORS.*

By S. W. Melsom, Associate Member, and H. C. Booth.

[From the National Physical Laboratory.]

(*Paper first received 9th February, and in final form 27th May, 1922.*)

Summary.

The object of the investigation was to determine the amount of the contact resistance between the surfaces of an overlapping joint in rectangular straight busbar conductors of copper and aluminium under various conditions of surface preparation and pressure, and hence to ascertain the efficiency of such joints. An efficient joint was regarded as one in which the total resistance, which includes effects due to stream-line distortion, does not exceed that of an equal length of continuous conductor on either side of the joint. As a preliminary it was necessary to determine and allow for the effect of stream-line distortion under various conditions of overlap. Generally full-sized models were investigated, and the two surfaces with varying amounts of overlap were pressed together by means of an hydraulic ram or by bolts or special clamps. Numerical results are deduced and tables and graphs given for the contact resistance per unit of surface area under various conditions of pressure and amount of overlap, and after various modes of clean ng and preparing the surface, including the interposition of tinfoil or the soldering of the two bars together. A series of graphs are given which show the efficiency of copper and aluminium joints in terms of the above defined standard for a wide range of values of busbar sizes and for any value of specific contact resistance likely to occur under practical conditions, and hence the amount of overlap required to obtain an efficient joint. The efficiency of making joints by means of clamps and bolts was also considered and the pressure occurring at such joints estimated by comparison of the contact resistance obtained when the same joint was held together in the hydraulic press. The effect of modifying the numbers, size and position of the bolts used was also investigated.

The typical form of a clamped joint between flat conductors of rectangular cross-section is shown in Fig. 1. The data required should enable the resistance of the overlapping portion A_1 A_2 to be calculated, and the ratio of its resistance to that of an equal length of single conductor of the same cross-section and resistivity to be predetermined.

The problem under consideration divides itself into two heads:

(1) The increase of resistance due to the stream-line distortion which occurs at the overlap.

(2) The contact or transition resistance between the superposed metal surfaces, and the manner in which this is affected by pressure and area of contact, and the condition or mode of preparation of the surfaces.

* The Papers Committee invite written communications (with a view to publication in the *Journal* if approved by the Committee) on papers published in the *Journal* without being read at a meeting. Communications should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

(1) The Effect of Stream-line Distortion.

If the length of overlap is large compared with the thickness of the bar, the metallic resistance of the overlapping portion will obviously be very nearly equal to that of two conductors in parallel. But if the overlap is much reduced this ceases to be strictly true, as, owing to the distortion of the stream lines, the resistance is greater than that of two bars in parallel. It will be obvious that this distortion depends only on the ratio of the overlap to the thickness of the bar, and, provided the two bars are of equal width, it will

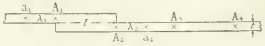

Fig. 1.

not be affected by the width; the current-flow can therefore be regarded as taking place in two dimensions only. To determine the magnitude of this effect a series of experimental observations were made by means of a tinfoil model. A piece of thin, uniform tinfoil was cut into a shape which represented the longitudinal section of an overlap joint (Fig. 1). A steady current of suitable strength was passed through the strip, and the voltage-drop v_1 between the points A_1, A_2 was

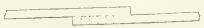

Fig. 2.

compared by means of a potentiometer or millivoltmeter with the voltage-drop v_2 between the two points A_3, A_4, placed an equal distance apart in the straight portion of the strip. Since the voltage-drop is proportional to the resistance, the factor $\sigma = v_1/v_2$ expresses the increase in metallic resistance due to stream-line distortion. This value is clearly constant whatever the dimensions of the overlap, provided that the ratio of the length l to the thickness t remains the same. To determine σ for other values of the overlap ratio l/t, the tinfoil was cut away as indicated by the dotted lines in Fig. 2. In this way a series of values were obtained for the ratio l/t, and for each of these values the resistance ratio σ was determined. A sufficient number of

values was obtained to enable the curve in Fig. 3 to be drawn. This shows graphically the relation between σ and the overlap ratio l/t. If, for example, the overlap is 10 times the thickness of the bar, the increase of resistance due to distortion effect is only 4 per cent, but if the overlap is 4 times the thickness, the increase is approximately 20 per cent, and, where it is only twice the thickness, it is nearly 50 per cent. As will be seen later, a knowledge of the relation between σ and the ratio l/t was also necessary in deducing the true contact resistance from the experimental results.

It is perhaps of interest to note that by a slight modification of the procedure it is possible to trace out the equipotential lines over the joint section as represented by the tinfoil model. Another series of lines drawn at right angles to these will then represent the general form of the stream lines of current-flow in an actual joint. This involves the assumption that if there were a joint in the circuit, instead of the metal being continuous, the distribution of the stream lines would not be appreciably affected. As will be shown

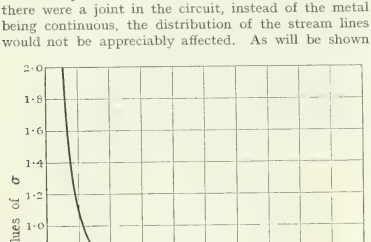

FIG. 3.—Showing effect of stream-line distortion in overlapping joints.

later, the magnitude of the contact resistance in a satisfactory joint is sufficiently low to justify this assumption.

Tee joints.—The question of the distortion of stream lines in a T joint is a much more difficult one, since the distortion is in three dimensions, the compound effect being due to:

(*a*) Distortion owing to change of direction from the horizontal to the vertical strip, and

(*b*) Distortion produced by the fact that the bars are not in the same plane.

To meet this case, an actual determination was made with a T joint between two pieces of copper 2 inches $\times \frac{3}{8}$ inch, the joint being soldered in order to reduce the contact resistance to a low and uniform value. Comparison was then made between the resistance of this joint and that of a straight-on soldered joint having the same amount of overlap and made in a similar way. It was found that the values were not greatly dissimilar.

(2) Contact Resistance.

The contact resistance between a prepared, flat metal surface is dependent on a number of factors, e.g. pressure, the area of the surfaces in contact, and the mode of preparation of the surfaces themselves, all of which require to be investigated.

The assumption commonly made is that a contact between any two surfaces is at three points only, which would lead to the conclusion that if the total pressure remained the same the contact resistance would be independent of the area of the two surfaces pressed together, but all the experiments which were made showed that in copper and aluminium bars clamped together under the pressures used in practice, the contact resistance was more nearly inversely proportional to the area when the pressure per unit area was the same. This is most apparent in the values given for the 1 inch $\times \frac{1}{4}$ inch copper bar (Table 8), where a decrease of overlap resulted in a large decrease in contact resistance. On the three-point contact theory the contact resistance should have remained the same, since the total applied pressure on the assumed three points would have been the same.

With a very small pressure the three-point contact theory would probably apply, but with any appreciable pressure it seems probable that there is some deformation, either by straining or flowing of the metal. In fact, an inspection of the bars after they had been clamped together suggested that this was the case. It will be realized that contact resistance is a function of the thickness of the film of air between the two surfaces. This thickness is, of course, in any case exceedingly small and a very slight variation of it would affect the value of contact resistance to a very large extent.

The assumption made in interpreting the results given in this paper, i.e. that the resistance between two surfaces is inversely proportional to the area when the pressure per unit area is the same, may not be absolutely correct, but it appears more nearly to represent the facts.

Experimental Methods.

The values given in this paper are all based on measurements on actual copper and aluminium bars of various sizes, up to and including bars 6 inches $\times \frac{1}{2}$ inch thick. Kraus * described an ingenious method of determining contact resistance by superposing a number of thin discs of metal in order to magnify the effect. This method appeared to be well suited for laboratory purposes, and seemed good since it would enable the contact resistance to be determined directly. The method was tried, but we failed to obtain any reasonable degree of consistency. Quite apart from this, however, the use of full-scale bars is to be preferred, since it is clear that other factors which affect the result are not operative when a small-scale model is employed. It will, however, be realized that the method adopted involves the evaluation of the contact resistance as a difference between two larger quantities. In any case the contact resistance is a most variable

* *Elektrotechnik und Maschinenbau*, 1920, vol. 38, p. 1.

quantity, and the accuracy of the observations was usually much higher than the consistency of individual determinations.

The method generally adopted was to form an overlapping joint by bolting, clamping, or pressing together by means of a hydraulic ram, a pair of flat bars of similar cross-section. This also allowed of investigation of the effect of preparing the surfaces under the various conditions obtainable in practice and of other methods of preparation that appeared likely to give better results.

Two contact terminals were fixed at points a_1, a_2 (Fig. 1), each usually at a small distance λ_1, λ_2 on either side of the joint. The voltage-drop between these terminals was measured by means of a potentiometer when a known current was flowing through the joints; the resistance was calculated and a correction was then made by subtracting (1) the resistance of that part λ_1 and λ_2 of the single conductors which was included between A_1 and a_1, and A_2 and a_2; and (2) the resistance of a piece of single conductor equal in length to the overlap multiplied by the appropriate value of σ as given by the curve in Fig. 3, in order to correct for the effect of stream-line distortion. The residual amount was then considered to represent the contact resistance between the surfaces.

Thus, if the resistivity of the metal is r and if $\lambda = \lambda_1 + \lambda_2$ (the sum of the lengths of single conductor included between A_1 a_1 and A_2 a_2 respectively); and if b is the breadth and t the thickness of the bars, then the resistance of this portion will be

$$r\lambda/bt$$

and, if l is the overlap, the resistance of the overlap portion considered as a solid piece of metal without contact resistance would be

$$\sigma rl/bt$$

where σ is taken from the curve (Fig. 3) for the particular value of l/t under consideration.

Then if R_t is the total resistance as measured between the points a_1 and a_2, the true contact resistance will be

$$R_t - [(\lambda + \sigma l)r/bt]$$

In order to facilitate the comparison and application of the results obtained, it is further assumed that under such pressures as are used in practice the contact between the surfaces will be fairly complete, and also that the resistance is inversely proportional to the area of the contact surfaces. On this assumption the specific contact resistance or resistance per unit area will be

$$\rho = \left\{ R_t - [(\lambda + \sigma l)r/bt] \right\} lb$$

and this formula was generally employed to deduce the specific contact resistance from the results obtained in the experimental investigations on clamped joints.

In the majority of these experimental determinations the overlap joint was pressed directly into contact by means of an hydraulic ram, which was capable of producing a maximum total pressure of about 10 tons, indicated on an attached pressure gauge. The two ends of the bars which were to form the joint were previously trued up so that when brought together the outer surfaces to which pressure was applied might be very fairly parallel. Flat pieces of ebonite or Stabilit were placed above and below the overlap. These insulated the joint from the plates of the ram, and at the same time their greater plasticity served to equalize the distribution of the applied pressure in the event of the two outer surfaces of the joint not being exactly parallel.

The measurement of the actual resistance of the joint was made under a series of progressively increasing pressures, but in order to obtain more stable conditions the maximum permissible pressure was usually applied several times before a measurement was made. On the assumption that the pressure on the superposed surfaces is evenly distributed, the specific pressure p is equal to the total indicated pressure P divided by the total area of contact, that is $p = P/lb$.

Tests on Aluminium Busbars.

The tests on the aluminium busbars were made on behalf of the British Aluminium Company, whom we have to thank for permission to publish the results.

Preparation of the surfaces.—The contact resistance of aluminium is necessarily influenced to a very large extent by the slight film of oxide normally present on the surface. This oxide forms so rapidly that the usual method of cleaning the bars and immediately clamping them together is not satisfactory. In these experiments the first satisfactory result was obtained with bars the ends of which were cleaned and bolted together under paraffin oil. This is, of course, not a practicable method for ordinary use, but it indicated the nature of the precautions that had to be taken, and led to the evolution of methods which could be readily applied to practical conditions, and which gave equally satisfactory results. Apart from the question of the removal of oxide, the results were affected also by the nature of the surface, e.g. whether it was dead smooth or rough from the file.

The surfaces were therefore tested under a variety of conditions, i.e.

(1) Bars carefully flatted and left rough; and
(2) Bars carefully flatted and smoothed;

and in both cases the contact resistance was determined when the surfaces were pressed together

(*a*) Without further preparation;
(*b*) After cleaning with emery paper and paraffin, the metal surfaces being cleaned and brought together under paraffin so as to reduce the amount of oxidation to a minimum; and
(*c*) When cleaned with emery and protected with a thick layer of clean vaseline.

Numerical results obtained with the various types of surface.—The results obtained for contact resistance with the various types of surface at pressures varying from 1 000 to 10 000 lb. per square inch are given in Fig. 5 and are summarized in Table 1.

TABLE 1.

Nature and condition of surface		Contact resistance: microhms per sq. in. at 2 000 lb./sq. in.	3 000 lb./sq. in.	4 000 lb./sq. in.	5 000 lb./sq. in.
(1) Flatted rough	(*a*) Without special cleaning ..	15	11	8	7·7
	(*b*) Emery paper and paraffin ..	5·8	4·0	3·2	2·8
	(*c*) Emery paper and vaseline	5	3·7	3·4	3·2
(2) Flatted smooth	(*a*) Without special cleaning ..	Results extremely variable			
	(*b*) Emery paper and paraffin ..	12	8	6	4·8
	(*c*) Emery paper and vaseline	8·5	5·5	3·5	2·5

These values represent the mean of a large number of determinations; at the lower pressures the results of individual observations showed considerable variations, but at the higher pressures these were quite fairly consistent and reproducible. Under practical conditions, as will be shown later, the actual pressure occurring in a bolted joint is approximately equivalent to a value of from 1 000 to 2 000 lb. per square inch, according to the size of the joint and the number and size of bolts used to make the connection, and, in view of the variations at these pressures and the divergencies found when bars not specially machined are used, curve F (Fig. 4) has been drawn as representing average values for joints prepared under various conditions, although it is clear that lower values can be obtained if the surfaces are properly prepared.

TABLE 2.

Test No.	Type of surface	Contact resistance: microhms per sq. in.
	Machine-flatted surfaces.	
1	Coated with vaseline; cleaned with a file and clamped up without removing vaseline	4·8
2	Rough-filed dry, coated with vaseline, cleaned with emery paper and clamped without removing vaseline	2·8
3	As 2, but with vaseline removed	4·0
4	Test 2 repeated	3·2
5	Test 1 repeated	3·4
6	As (1), but the surfaces left apart for 1 hour before	4·5
7	As (6), wiped clean and reassembled	7·4
	Original surface of the strip, as delivered from the rolls.	
8	Wiped with cotton cloth only	15·5
9	Smeared with vaseline, rough-filed and clamped without removing vaseline	4·2
10	As (9), but with dirty vaseline removed	5·8
11	Coated with vaseline, cleaned with emery paper and clamped without removing vaseline	3·0
12	As (11), but with vaseline removed	4·2
13	Test 11 repeated	5·0
14	Dirty vaseline removed and replaced by clean	6·7

In order to meet the question of the practical use of busbars where the work of cleaning and preparing the surfaces will have to be carried out on site, a detailed series of observations was made with slight modifications in the mode of preparation. The same bars were used throughout, and the overlap and applied pressure were in all cases the same, the pressure being 3 700 lb. per square inch. These results are given in Table 2.

The only obvious inconsistency in this table is in Test No. 13, where the results are rather higher than would be expected. Generally, however, the results show a remarkable degree of consistency, and it is clear from them that the easiest method of preparation in practical work, i.e. rough cleaning with a file either (*a*) before the vaseline is applied, and cleaning afterwards with emery, or (*b*) coating with vaseline and rough filing, in both cases leaving the dirty vaseline on the bar, is at least as good as, if not better than, any other method

Amount of overlap required.—In considering the amount of overlap required to make an efficient joint, it is most convenient to express the resistance of the joint as a compound effect made up of the contact resistance and the metallic resistance, as modified by the stream-line distortion. This is best stated in terms of the resistance of an equal length of the straight conductor. Thus, an efficient joint is one in which the total resistance of the length comprising the joint is not greater than that of an equal length of the straight conductor.

On the assumption that the contact resistance between two flat metal surfaces is inversely proportional to the area of contact, the total resistance of an overlapping joint is

$$R = r\sigma l/bt + \rho l/bl$$

where the symbols have the meanings already defined (the distortion factor σ having the appropriate value

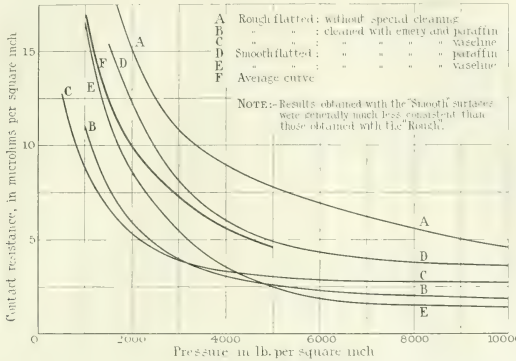
A Rough flatted: without special cleaning.
B " " : cleaned with emery and paraffin
C " " : " " " vaseline
D Smooth flatted: " " " paraffin
E " " : " " " vaseline
F Average curve
NOTE:-Results obtained with the "Smooth" surfaces were generally much less consistent than those obtained with the "Rough."
Contact resistance, in microhms per square inch
Pressure in lb. per square inch
0
5
10
15
2000
4000
6000
8000
10000

FIG. 4.—Showing variation of specific contact resistance with pressure, for aluminium.

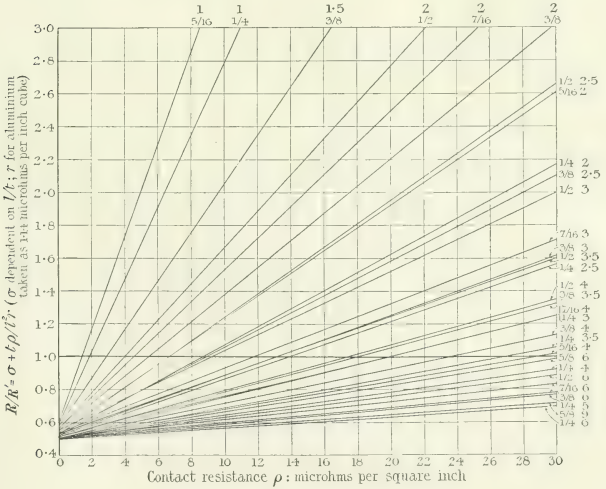

FIG. 5.

for the ratio l/t, as given in Fig. 3. The resistance of an equal length l of single, straight conductor is

$$R' = r l/bt$$

therefore the ratio of the two resistances is

$$R/R' = \sigma \div (\rho t l/r)$$

that is, a linear function of ρ.

In Fig. 5, a series of straight-line graphs have been drawn, taking r the resistivity of aluminium as 1·14 microhms per inch cube, which shows the value of R/R' considered as a function of ρ for a series of values of length of overlap l and thickness of strip t as indicated in the top and right-hand side of the figure.

Tables 3 and 4 give the values for the various thicknesses of bar, and overlap ratio l/t for the same values of pressure and contact resistance as in the two cases just quoted. These tables also show separately the magnitude of the two components of the total contact resistance. These are $\rho l/b$, the contact resistance between the surfaces, and $\sigma r l/bt$, the metallic resistance of the joint, allowing for the distortion effect.

Tables 3 and 4 are based on a strip 1 inch wide. Their application to bars of other widths may be shown by taking the case of a busbar 3 inches wide and $\frac{3}{8}$ inch thick, with an overlap of 3 inches. In this case l/t would be 8. Then, assuming a pressure of 2 000 lb. per square inch from Table 3, the value of

TABLE 3.

Joint Pressure: 2 000 *lb. per square inch.* $\rho = 10$ *microhms per square inch.*

l/t	R'	$\sigma R'$	$\rho l/b$			$R = \sigma r l/bt + \rho l/b$					R/R'			
			$t = \frac{3}{8}$	$t = \frac{1}{2}$	$t = \frac{3}{4}$	$t = \frac{3}{8}$	$t = \frac{1}{2}$	$t = 1$	$t = 1\frac{1}{2}$	$t = 2$	$t = \frac{3}{8}$	$t = \frac{1}{2}$	$t = 1$	$t = 1\frac{1}{2}$	$t = 2$
4	4·56	2·68	6·67	5·00	4·00	3·35	9·35	7·68	6·68	6·03	2·05	1·68	1·47	1·32	
6	6·84	3·68	4·45	3·35	2·67	2·23	8·13	7·03	6·35	5·91	1·19	1·03	0·93	0·87	
8	9·12	4·73	3·35	2·50	2·00	1·67	8·08	7·23	6·73	6·40	0·89	0·79	0·74	0·70	
12	13·68	6·95	2·23	1·67	1·35	1·11	9·18	8·62	8·30	8·06	0·67	0·63	0·61	0·59	

TABLE 4.

Joint Pressure: 4 000 *lb. per square inch.* $\rho = 5{\cdot}6$ *microhms per square inch.*

l/t	R'	$\sigma R'$	$\rho l/b$				$R = \sigma r l/bt + \rho l/b$				R/R'				
			$t = \frac{1}{2}$	$t = \frac{3}{4}$	$t = \frac{3}{8}$	$t = 1$	$t = \frac{3}{8}$	$t = \frac{1}{2}$	$t = \frac{3}{4}$	$t = 1$	$t = \frac{1}{2}$	$t = \frac{3}{4}$	$t = 1$	$t = 1\frac{1}{2}$	$t = 2$
4	4·56	2·68	3·74	2·80	2·24	1·88	6·42	5·48	4·92	4·56	1·41	1·20	1·08	1·00	
6	6·84	3·68	2·50	1·88	1·49	1·24	6·18	5·56	5·17	4·92	0·90	0·81	0·75	0·72	
8	9·12	4·73	1·88	1·40	1·12	0·93	6·61	6·13	5·85	5·66	0·73	0·67	0·64	0·62	
12	13·68	6·95	1·24	0·93	0·75	0·62	8·19	7·88	7·70	7·57	0·60	0·58	0·56	0·55	

As an example of the use of the graphs, taking the value of contact resistance from curve F in Fig. 4 as 10 microhms per square inch for a pressure of 2 000 lb. per square inch, then in the case of a joint in a strip $\frac{1}{2}$ inch thick with an overlap of 3 inches, $R/R' = 1{\cdot}03$; for a 4-inch overlap $R/R' = 0{\cdot}79$; and for a 6-inch overlap $R/R' = 0{\cdot}63$. For a pressure of 4 000 lb. per square inch, the contact resistance would be 5·6 microhms per square inch, and the values of R/R' for the same three cases would be 0·79, 0·67 and 0·57, respectively.

In order to show the relative magnitude of the two factors involved in the resistance of an overlapping joint, Tables 3 and 4 have been drawn up. These show the ratio R/R' for a contact resistance of 10·0 microhms per square inch and 5·6 microhms per square inch, corresponding to pressures of 2 000 and 4 000 lb. per square inch, respectively.

R for $t = \frac{3}{8}$ inch and $l/t = 8$ is found to be 8·08 microhms. Thus, for a bar 3 inches wide, this resistance should be 8·08/3, assuming, of course, the same pressure per square inch in each case, and the total resistance of the joint is 2·69 microhms. The ratio of the resistance of the joint to that of a similar length of straight conductor is the same as that given in Table 3, viz. 0·89.

TESTS ON COPPER BUSBARS.

The properties of copper as regards contact resistance would appear to be somewhat different from those of aluminium. This may be, first, because copper is not so liable to oxidation at ordinary temperatures, and secondly, it is harder, and on this account its behaviour will not necessarily be the same as that of a more yielding material.

Somewhat the same series of tests were carried out

to ascertain the effect of the condition of the surface and the applied pressure, and a series of results, show-

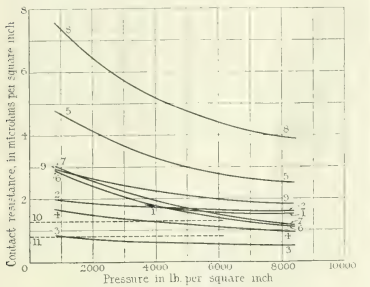

FIG. 6.—Showing comparative effect of various modes of preparation. Test taken on 1 in. × ¼ in. copper strip without preliminary machining.

1. Rubbed with dry emery paper.
2. Rubbed with dry emery paper but wiped with cotton waste after rubbing
3. Rubbed with vaseline and emery paper.
4. Vaseline removed; roughened with file.
5. Vaseline removed; roughened with file.
6. Vaseline removed; roughened with file
7. One thickness of tinfoil interposed.
8. Two thicknesses of tinfoil interposed
9. The surfaces previously tinned.
10. The joint soldered
11. The joint taken apart and re-soldered

ing the contact resistance under the various conditions, are given in Fig. 6. It will be noted that:

(1) As in the case of aluminium, the best results are obtained when the surface is coated with vaseline, although in most cases the results are so low that this method of treatment is not necessary in practice.

(2) The values obtained with a joint pressed together after cleaning with vaseline are as good as when the joint is soldered.

(3) The interposing of layers of tinfoil between the surfaces has a marked effect: one thickness of the foil does not affect the results largely, but with two thicknesses the contact resistance is very much higher.

(4) There is no appreciable improvement due to roughening the surface with a file. In one case the results were somewhat better, but in others they were worse than when the surfaces were left smooth and cleaned with emery paper.

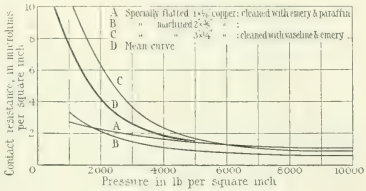
A Specially flatted 1×½ copper: cleaned with emery & paraffin
B " hurriflated 2×⅜ " : "
C " " 3×⅛ " : cleaned with vaseline & emery
D Mean curve
Contact resistance, in microhms per square inch
Pressure in lb per square inch
0
2000
4000
6000
8000
10000

FIG. 7.—Showing varieties of specific contact resistance with pressure, for copper.

Generally, it will be seen that the values shown in the figure are in most cases very low but, in view of the variable nature of contact resistance, too much

TABLE 5.

Joint Pressure: 2 000 *lb. per square inch.* $\rho = 4{\cdot}0$ *microhms per square inch.*

lb	R'	$\sigma R'$	ρ/lb				$R = \sigma\rho/lb + \rho/ld$				R/R'			
			$t = \frac{3}{8}$	$t = \frac{1}{2}$	$t = \frac{5}{8}$	$t = \frac{3}{4}$	$t = \frac{5}{8}$	$t = \frac{3}{4}$	$t = \frac{7}{8}$	$t = 1$	$t = \frac{1}{2}$	$t = \frac{5}{8}$	$t = \frac{3}{4}$	
4	2·72	1·60	2·67	2·0	1·6	1·33	4·27	3·60	3·20	2·93	1·57	1·32	1·17	1·08
6	4·08	2·20	1·78	1·33	1·07	0·89	3·98	3·53	3·27	3·09	0·97	0·86	0·80	0·76
8	5·44	2·82	1·33	1·00	0·80	0·67	4·15	3·82	3·62	3·49	0·76	0·70	0·67	0·64
12	8·16	4·16	0·89	0·67	0·53	0·445	5·05	4·83	4·69	4·60	0·62	0·59	0·57	0·56

TABLE 6.

Joint Pressure: 4 000 *lb. per square inch.* $\rho = 1{\cdot}8$ *microhms per square inch.*

lb	R'	$\sigma R'$	ρ/lb				$R = \sigma\rho/lb + \rho/ld$						R/R'			
			$t = \frac{3}{8}$	$t = \frac{1}{2}$	$t = \frac{5}{8}$	$t = \frac{3}{4}$	$t = \frac{3}{8}$	$t = \frac{1}{2}$	$t = \frac{5}{8}$	$t = \frac{3}{4}$	$t = \frac{7}{8}$	$t = 1$	$t = \frac{1}{2}$	$t = \frac{5}{8}$	$t = \frac{3}{4}$	
4	2·72	1·60	1·20	0·90	0·72	0·60	2·80	2·50	2·32	2·20	1·30	0·92	0·85	0·81
6	4·08	2·20	0·80	0·60	0·48	0·40	3·00	2·80	2·68	2·60	0·74	0·69	0·66	0·64
8	5·44	2·82	0·60	0·45	0·36	0·30	3·42	3·27	3·18	3·12	0·63	0·60	0·585	0·573
12	8·16	4·16	0·40	0·30	0·24	0·20	4·56	4·46	4·40	4·36	0·373	0·365	0·360	0·355

weight must not be given to what may appear to be large variations.

It will be seen that this particular series was obtained with a strip of copper 1 inch × $\frac{1}{4}$ inch; further tests, however, with sizes up to 6 inches × $\frac{1}{2}$ inch give closely comparable results.

As with aluminium, however, fairly large variations were found with copper strip straight from the rolls and without special machining, and curve D (Fig. 7) has therefore been added as being fairly representative of practical conditions.

Amount of overlap required.—The method of determination of the amount of overlap required for an

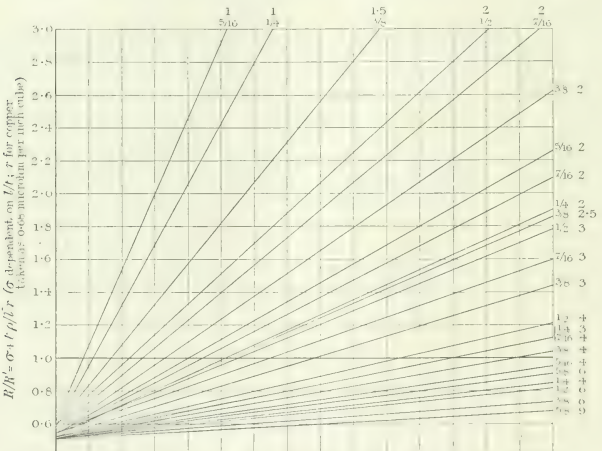

FIG. 8.

inch and 4 000 lb. per square inch, the values would be 0·76 and 0·69, respectively. Tables 5 and 6 give the values for the various thicknesses of bar and overlap ratio l/t for values of contact resistance corresponding to pressures of 2 000 and 4 000 lb. per square inch, respectively.

Clamped joints.—The determination of contact and joint resistance with relation to the pressure is not of itself sufficient to solve the problem arising in practice. The further step required is to ascertain the effective pressure exerted by the clamps and bolts used in the ordinary busbar joint.

For this determination the surfaces of the bars were

efficient joint will be the same as in the case of aluminium bars, although of course two of the factors—resistivity and contact resistance—will be somewhat different. Stream-line distortion will clearly be the same for bars of similar section and overlap. The graphs in Fig. 8 have been drawn in the same way as for aluminium, taking the resistivity of copper as 0·68 microhm per inch cube.

Examples of the use of the graphs are as follows:—Taking the specific normal contact resistance of the prepared surfaces shown in curve D (Fig. 7), i.e. 4·2 microhms per square inch with a pressure of 2 000 lb. per square inch, then for a strip $\frac{1}{2}$ inch thick with an overlap of 3 inches, the ratio $R/R' = 0·89$, and for the same joint with pressures of 3 000 lb. per square

prepared under the best conditions, and tests were made alternately with them pressed together in the ram and when clamped or bolted together.

Only two sizes of clamps were available, one suitable for a bar 3 inches wide, and the other for a bar 2 inches wide, and these were tested with aluminium bars 3 inches × $\frac{3}{8}$ inch and 2 inches × $\frac{1}{4}$ inch.

The clamps were provided with four steel bolts, one at each corner, the sizes of bolts being $\frac{1}{2}$ inch and $\frac{3}{8}$ inch, respectively. During the tests the clamps were insulated from the bars by means of a thin sheet of hard insulating material. In actual practice they would be in metallic contact with the bars and, in consequence, would improve the joint slightly, but in this case we were endeavouring to make a determination

of the much more important factor of pressure and, for the sake of uniformity, it was desirable to eliminate this somewhat uncertain factor.

Taking first the 3-inch clamps, with an overlap of 3 inches in an aluminium bar, the contact resistance was 0·88 microhm, the total joint resistance 2·6 microhms, and the corresponding ratio $R/R' = 0·79$. The pressure by ram for an equivalent value would be about 10 800 lb., or 1 200 lb. per square inch. It is interesting to note that with the clamp the joint resistance was only 0·79 time that of an equivalent length of straight conductor, and that even with the higher value of contact resistance indicated by the average curve F in Fig. 4, viz. 15 microhms per square inch with a pressure of 1 200 lb. per square inch, the ratio R/R' would be very nearly 1.

Some tests were made with this clamp before the strips were protected with vaseline and cleaned, and the results may be quoted to emphasize the importance of the preparation of the surfaces. With the bars in their initial condition the contact resistance was 3 microhms and the ratio $R/R' = 1·4$, as compared with 0·88 and 0·79 when the surfaces of the bars were properly prepared. It should, however, be noted that with thicker bars the ratio R/R' would be greater and, under the average conditions quoted, probably more nearly 1·2. In the case of an interleaved joint made with a number of pairs of bars pressed together by a single clamp, it would seem probable that the joint ratio would be the same as that for a single pair of bars under the same conditions of overlap.

With the 2-inch clamps, and the smaller bar with an overlap of 3 inches, the contact resistance was 1·7 microhms, the joint resistance 6·9 microhms, and the corresponding ratio $R/R' = 0·69$. The same joint tested immediately afterwards in the hydraulic ram showed that the pressure of the clamps was about 2 000 lb. per square inch.

Bolted joints.—The actual pressure exerted by a bolt or by a number of bolts clamping two pieces of metal together has not up to the present been clearly defined. We have, on the one hand, definite information as to the breaking stress for bolts of various sizes, and it was hoped that this investigation would show the actual effective pressure exerted when a bolt, or bolts, were used instead of the hydraulic ram. The assumption was that if two bars previously drilled and prepared were first clamped in the ram with a known pressure, a comparison of the joint resistance under the same conditions with that obtained when the same bars were bolted together would give an approximate indication of the actual pressure exerted by the bolts. The pressures so indicated, however, in some cases exceed the elastic limit of the bolt, and it would appear that with comparatively thin bars the pressure is localized and more effective than with the ram or with clamps. If the bars were very thick and rigid it is probable that there would be no great difference between the two conditions, but with bars of the range of thickness ordinarily used in practice it seems probable that the pressure produced by the bolts may strain the metal to an extent sufficient to bring about a more intimate contact. The effect of bolting two comparatively thin bars together probably results in bending the metal around the bolt to a very slight extent when expressed in actual measurement, but sufficient to affect the contact resistance considerably. When the joint is made with a number of bolts, the slight bending of the strip at or near each bolt possibly produces a lateral motion which of itself would tend, by grinding the surfaces together, to break down the air film.

Taking, first, aluminium with a bar 3 inches wide and $\frac{7}{16}$ inch thick, the following values were obtained under the standard conditions of surface, i.e. roughened and then coated with vaseline and cleaned with emery.

TABLE 7.

Pressure by	Contact resistance, in microhms	Joint resistance, in microhms	Ratio: R/R'
Overlap = 3 inches.			
Four $\frac{3}{8}$-inch brass bolts			
Initial	1·4	3·18	0·97
After 1 day	1·2	2·94	0·89
After 2 days	1·2	2·94	0·89
After 4 weeks	1·35	3·10	0·94
Four $\frac{1}{2}$-inch steel bolts ..	1·3	3·00	0·91
Overlap = 1$\frac{1}{2}$ inches.			
Two $\frac{1}{2}$-inch steel bolts ..	2·06	3·07	1·87

Thus with a bar of this thickness and an overlap of 3 inches the predetermined figure obtained by means of the graphs for a pressure of 2 000 lb. per square inch and a contact resistance of 10 microhms per square inch would be $R/R' = 0·92$, which is in good agreement with the values given above for a bolted joint.

Comparing these results with values obtained with the hydraulic press, it would appear that four $\frac{3}{8}$-inch bolts produce a pressure equal to 2 000 lb. per square inch, and that there was no great difference in this particular case between $\frac{3}{8}$-inch bolts and $\frac{1}{2}$-inch bolts.

Copper.—A large number of tests were made with copper bars to determine the effect of bolting in various ways and the effective pressure exerted by bolts.

(1) Taking, first, small strips 1 inch × $\frac{1}{4}$ inch clamped together with a $\frac{3}{8}$-inch steel bolt, the values obtained were as given in Table 8.

TABLE 8.

Length of overlap, inches ..	2	1·5	1
Contact resistance, microhms ..	2·25	1·67	0·89
Joint resistance	5·0	3·8	2·35
Value of R/R'	0·95	0·95	0·94

With an overlap of 1 inch the pressure, applied by ram, corresponding to the values given above was 3 000 lb. per square inch.

It will be noted that in this case, although the ratio R/R' was practically constant for any overlap, the

contact resistance decreased with the smaller overlap with a consequent increase of pressure per unit area.

TABLE 9.

Overlap	Number and size of bolts	Contact resistance	Joint resistance	Value of R/R'
inches		microhms	microhms	
3	2 × $\frac{5}{8}$ inch	0·38	0·75	1·07
		0·36	0·73	1·04
		0·39	0·76	1·09
		0·35	0·76	0·97
3	2 × $\frac{3}{4}$ inch	0·43	0·84	0·99
		0·44	0·85	1·09
		0·45	0·86	1·10
6	2 × $\frac{5}{8}$ inch	0·54	1·26	0·90
		0·29	1·01	0·72
		0·28	1·60	0·71
		0·18	0·90	0·64
		0·37	1·06	0·74
6	4 × $\frac{5}{8}$ inch	0·41	1·20	0·77
		0·19	0·91	0·65
		0·35	1·14	0·73
		0·21	0·93	0·66
		0·17	0·87	0·64
6	5 × $\frac{5}{8}$ inch	0·35	1·14	0·73
		0·5	1·28	0·82
6	2 × $\frac{3}{4}$ inch	0·57	1·36	0·87
		0·34	1·13	0·72
		0·42	1·20	0·77
		0·47	1·23	0·79
6	4 × $\frac{3}{4}$ inch	0·33	1·12	0·72
		0·37	1·16	0·74
		0·29	1·08	0·69
		0·36	1·15	0·74
6	5 × $\frac{3}{4}$ inch	0·29	1·08	0·69
		0·36	1·15	0·74

(2) *An experiment directed solely to determine the pressure exerted by a bolt.*—Strips of copper 2 inches × $\frac{3}{8}$ inch were clamped together by a single $\frac{5}{8}$-inch bolt.

Length of overlap, inches	..	2
Contact resistance, microhms	..	0·76
Joint resistance, microhms	..	1·70
Value of R/R'	..	0·96

With the ram the pressure required to produce the same values was 2 300 lb. per square inch.

(3) Tests were made with a joint of 6-inch × $\frac{1}{4}$-inch copper strip to determine the effect of varying the number of bolts used. The results are given in Table 9.

Further tests were made to compare the joint resistance with a single 1-inch bolt and special washers 4 inches in diameter, lent by Dr. Fleck, with the values for a 4 × $\frac{3}{4}$-inch bolt joint. The surfaces of the copper were carefully cleaned and special precautions were taken to ensure that all the bolts were fully tight. The results are given in Table 10.

While the paper gives values which it is hoped will be of immediate use, it is clear that further work will have to be carried out on bolted joints, the results of which are somewhat conflicting. With the thinner strips the effective pressure for a given size of bolt is much higher than with the thicker strips, and observations of the surfaces after being clamped together would suggest that there is a slight bending of the material in the immediate neighbourhood of the bolts, which does not occur in the thicker strips. In the latter case, however, it is clear that a 4-inch overlap with four bolts makes a more effective joint than a 6-inch overlap, and also that while there was no great difference between 4 × $\frac{5}{8}$-inch bolts and 4 × $\frac{3}{4}$-inch bolts, the use of five bolts of either size did not improve matters. The use of a single 1-inch bolt specially tightened and used with large washers designed to spread the pressure over a large surface, gave a consistently higher value.

Heating of joints.—Assuming that the conditions necessary for making an efficient joint have been observed, it will be obvious that, since the radiating

TABLE 10.

Number and size of bolts	Overlap	Conditions	Contact resistance	Joint resistance	Value of R/R'
	inches		microhms	microhms	
4 × $\frac{3}{4}$ inch	6	Tightened with ordinary spanner	0·62	1·35	0·94
		Tightened with long spanner	0·51	1·28	0·85
1 × 1 inch	6	Tightened with special washers	0·62	1·39	0·92
1 × 1 inch	6	Tightened with very long spanner	0·73	1·50	0·99
			0·71	1·48	0·98
			0·79	1·56	1·03
			0·60	1·37	0·92
			0·71	1·48	0·98
			0·67	1·44	0·96
			0·75	1·52	1·01
			0·79	1·56	1·03
4 × $\frac{3}{4}$ inch	3·8	Tightened with ordinary spanner	0·21	0·71	0·73
1 × 1 inch	3·8	Tightened with ordinary spanner	0·55	1·05	1·08
			0·57	1·07	1·10
			0·57	1·07	1·10
1 × 1 inch	3·8	Tightened with ordinary washers	0·82	1·32	1·36

surface is larger, the temperature-rise at the joint will be less than that of the rest of the conductor.

Some actual observations made with a 3-inch × $\frac{5}{8}$-inch bar, the joints being made by means of the clamps already mentioned, showed that with a given current the temperature-rise at the joint was 22° C., while that of the conductor itself was 33° C. Results with other sizes of bars showed the same order of difference and in the same direction.

APPENDIX.

References to Joints and Contacts.

Binder, L.: "Der Widerstand von Kontakten." *Elektrotechnik und Maschinenbau*, 1921, vol. 30, p. 781.

Fleischbein, H. U.: "Neurungen an Kontakten und Kontakt Materialen." *Elektrotechnische Zeitschrift*, 1918, vol. 39, p. 445.

Harris, F. W.: "Electrical Contact Resistance," *Electric Journal*, 1913, vol. 10, p. 637.

Höpp, W.: "Die Berechnung von Kontakten." *Elektrotechnische Zeitschrift*, 1920, vol. 41, p. 205.

"Über den Kontaktwiderstand," *ibid.*, p. 910.

Kraus, F.: "Über den Kontaktwiderstand," *Elektrotechnik und Maschinenbau*, 1920, vol. 30, p. 1.

Richter, R.: "Untersuchungen über die Grösse und Beständigkeit von Kontaktverbindungen," *Elektrotechnische Zeitschrift*, 1920, vol. 41, p. 345.

Smith, I. B.: "Contact Resistance," *Journal of the Optical Society of America, and Review of Scientific Instruments*, 1922, vol. 6, p. 500.

DISCUSSION ON

"PROTECTIVE APPARATUS FOR TURBO-GENERATORS."*

The Author's Reply to the Discussions before the North Midland and North-Western Centres.

Mr. J. A. Kuyser (*in reply to the discussion before the North-Midland Centre*): Mr. Spurr's experience confirms the necessity for quick-acting protective gear. The property of the balanced-current protective gear that the generator cannot be operated if the gear is defective, is also a characteristic of the mid-point gear; the gear will operate if the potential transformers or leads are defective. Opinion on this subject seems to be divided, as this feature of the mid-point gear has been criticized as a disadvantage by another speaker. The extra tappings on the generator required in the mid-point gear do not constitute a very serious disadvantage. It is not necessary to bring out the two ends of the phase as in the case of balanced-current protection, and therefore three main leads, three mid-point leads and one star-point lead are required, i.e. a total of seven leads.

The proposal to clean and varnish the windings periodically is to be recommended to all users of turbo plant.

Mr. Carter confirms the statements made in the paper regarding accidental loss of field. The magnitude of the current drawn from the system under these conditions depends on the ratio between the no-load magnetizing ampere-turns and the armature ampere-turns, which in modern alternators is less than unity. When the field is interrupted the machine operates as an induction generator (or as a motor if the power supply is cut off), and the magnetizing current under these conditions will therefore be less than the normal current.

The question of a mid-point busbar in the station, to which all generator mid-points are connected, has been considered. There are some difficulties with this arrangement, in that special precautions must be taken to prevent the tripping of more than one generator. If always at least two generators are on the bars, no reactance coil would be required.

Mr. Frith's remarks on instrument transformers are dealt with by Mr. Buchanan. Whether it is necessary that a rotor must be so designed that the discharge resistance can be dispensed with, is questionable. In the case of a laminated rotor a resistance may be required; there is, however, the advantage that generally a larger resistance can be provided than would normally be given by the iron path of the solid rotor, and this would give a more rapid discharge. Different cooling fluids which would not sustain combustion have been proposed. The difficulty is to deal economically with the loss due to unavoidable leakage in the system.

In reply to Mr. Townend it is rather difficult to speculate as to the time required to establish a fire. My firm have had two short-circuits occurring on 25 000-kVA (approx.) alternators due to water carried over from a frozen air filter. The field switch limited the burning to a small amount in each case, and no fire was started.

The use of a short-circuiting switch similar to the flash-suppressor for rotary converters will accelerate the discharge appreciably, as can be estimated from Fig. 3, which illustrates the rapidity of the discharge in the case of a dead short-circuit on the terminals. A certain amount of extra switchgear would be involved with this arrangement.

In reply to Mr. Hill, if two earths developed

* Paper by Mr. J. A. Kuyser (see page 761).

simultaneously equidistant from the mid-point the voltage to earth would be different, and consequently the fault currents would be different, thereby causing unbalancing and tripping. Perfectly symmetric faults are considered non-existent in protective gear problems, e.g. in split-conductor protection. The rapidity of the break has very little influence on the induced voltage; tests made with a magnetic blow-out did not produce higher voltages than the ordinary circuit breaker.

Mr. Buchanan states the case for the instrument transformers. I feel certain that he agrees that reliable potential transformers could be produced, specially designed for the mid-point protective gear. As regards the possibility of producing Merz-Price transformers which will balance against each other, his statements that magnetically identical transformers can be produced will have to be put to the test, as up to the present accurately balanced cores have not been produced on a commercial scale. The subject is extremely important and will be further investigated.

The minimum current necessary for tripping the self-balancing gear depends on the following data: internal diameter of core; iron section in core; correct secondary winding and sensitivity of relay.

The figure of 40 amperes was obtained on a rather high relay setting. The relay in question can be tripped at 0·12 ampere and the tripping current can be correspondingly reduced, but at present a relay is on the market which will require approximately one-tenth of the tripping kilovolt-amperes, corresponding to a very very small primary tripping current. I agree that, in general, protective transformers and meter transformers should be kept separate.

The type of filter mentioned by Mr. Paxton appears to give satisfactory results up to the present, and, if this should continue to be the case, it would be suitable in those cases where the closed air-circuit system is at a disadvantage, more particularly where no suitable cooling water is available.

The proposal to provide a breathing duct in the closed system has already been considered and is worth further investigation, as a certain amount of air will leak out of the system and, if possible, this should be made up by cleaned air. The breathing action can be considered to be negligible as compared with the leakage. Trouble due to leakage from cooling coils is not likely if the coils are placed below the level of the machine; even if leakage should occur this would not be in the form of spray, and would not be carried over into the generator.

Mr. Williams raises an important point in connection with arcing on the rotor coil-retaining ring. This effect has been observed for a number of years and has not caused difficulties except in a case where other factors were probably more responsible.

Generally it is certainly preferable, although it may not be essential, to eliminate currents from the steel rings.

The proposal to cut a deep slot at the edge of the core, in order to interrupt the rotor surface currents, has already been considered. It is, however, extremely doubtful whether one single duct would serve the purpose; a large number, giving the effect of a laminated core, may be necessary to obtain the desired result. As regards the arcing, this would not occur when the field was opened, as the voltage in the rotor when this happened would be negligible compared with that generated in the case of a short-circuit on the stator terminals.

Mr. J. A. Kuyser (*in reply to the discussion before the North-Western Centre*): Mr. Cheetham points out the advantages of the Merz-Price gear, arranged with a specially sensitive earth-leakage relay. I agree that if the setting can be reduced to $7\frac{1}{2}$ per cent or less, the Merz-Price gear is not at such a great disadvantage compared with the self-balancing gear. Assuming that the self-balancing gear will operate at 20 amperes and the Merz-Price gear at $7\frac{1}{2}$ per cent, the two systems will be equivalent for a machine having a normal rated current at 266 amperes, corresponding to 1 500 kVA at 3 300 volts or 3 000 kVA at 6 600 volts; for larger machines the self-balancing gear gives more complete protection.

In reply to Mr. Lamb, the continuity of supply certainly merits as much consideration as the protection of the machine. In the case of direct versus indirect tripping of the field switch Mr. Lamb confirms that the tripping of the field on one of two duplicate machines did not cause a serious disturbance; once this is admitted there are strong arguments in favour of direct tripping.

The argument to make air dampers automatic is not so strong as in the case of the field switch; however, indicating apparatus or alarm devices are provided in connection with these dampers, which operate if the damper should trip during normal operation. Stator faults due to mechanical failures of the rotor have occurred in a few cases, more particularly where the rotor winding was held by banding wire. In the case of faults of this kind, the stator winding would generally be beyond repair even if the protective gear would operate. I should recommend not automatic steam injection, but hand-operated valves which would be used only in a last emergency if all the other protective gear failed.

It may be worth while to emphasize the importance of periodically testing the protective gear, to ensure that the protective gear can be depended upon to function properly.

In the closed air-circuit system, the necessary cooling water is sometimes not available. If water from the cooling ponds is used, it may be necessary during the hottest summer months to disconnect the closed air system and draw cool, but dirty, air directly from the atmosphere. This certainly constitutes a limitation to the closed air-circuit system.

I agree that in the case of large machines and low-voltage machines having one conductor per slot there is not much likelihood of a fault between turns. However, machines of 5 000 kW and smaller at 6 600 volts, or 10 000 kW at 11 000 volts, will have two or more conductors per slot and may develop a short-circuit between turns.

I understand that the majority of failures in transformers occur between turns, consequently there should still be a field for a protective gear which deals with these faults. It is true that the normal voltage between turns is only 250 volts or less, but in the case of disturb-

ances on the system the voltage across the end turns may reach values comparable with the system voltage. Further possibilities of faults between turns are metallic contact at the joints due to defective workmanship, or movement of the coils due to defective supports.

The use of potential transformers in the mid-point gear has to receive careful consideration. The ordinary commercial type would hardly be satisfactory, first on account of the unreliability, and secondly on account of too high internal reactance.

I am certain that, at an increased cost which would not be an objection when a large turbo set is involved, a reliable potential transformer can be manufactured. Extra reliability could be secured by insulating the core from the casing, and by the use of heavier and better insulated primary windings. In the case of a 10 000-volt generator, six potential transformers would be required, wound for 2 900 volts, which is a low voltage for a potential transformer.

It is correct that the generator will be cut out in the case of the failure of one of the potential transformers, but something similar will occur with the Merz-Price gear where the generator will be tripped if one of the pilot wires breaks, or a connection gets loose due to vibration. This fact is by some considered to be an advantage of the Merz-Price gear as compared with the self-balancing gear which has not this feature, as warning is given that the protective gear is defective and the set is running without protection. Faults of this kind are usually discovered directly a set is started up and before it has taken over the load.

Mr. Juhlin brings out the fact that high standards of design and workmanship in the turbo-alternators of to-day are not sufficiently good reasons for dispensing with protective gear. The statement has been made that advocacy of the use of protective gear is an admission of weakness in design; this attitude shows a lack of knowledge of the conditions under which turbo-alternators have to operate, and of the consequences of a failure.

In reply to Mr. Ratcliff, the figure of 200 amperes mentioned for the tripping current of the self-balancing gear is excessive. The reasons for this may be: (1) the incorrect winding of the coil or relay, (2) a core too small in section, or (3) relays not sensitive enough (20 amperes or less can easily be obtained). The mid-point gear is at present being tried under actual operating conditions, but the results are not yet available. As regards the definition of the self-induction coefficient, it is misleading and unnecessary to identify $d\Phi/dI$ and Φ/I, even if a qualifying statement is made. When discussing problems involving the rate of building up or discharging fields, I generally found that the mistake was made that L was determined from the saturation curve as $L = n(\Phi/I)10^{-8}$ instead of $L = n(d\Phi/dI)10^{-8}$, the reason for the mistake being the erroneous assumption that L is equal to the number of line linkages per unit of current. It would be desirable to omit this definition altogether from the literature on the subject. The voltage-rise on the slip-rings depends not on the formula for the rate of decrease of the current, but on the product of field current and R_d. The resistance in the iron path is not a very variable quantity in the case of similar rotors, e.g. solid rotors.

The value of this resistance in the case of solid rotors is always lower than that required to limit the voltage-rise to a safe value. Any addition of a discharge resistance is therefore undesirable for solid rotors. If the air circulation is interrupted in a turbo-alternator the temperature will increase to a dangerous value in approximately half an hour.

I agree with Mr. Ferguson that external reactances give a highly desirable protection to the winding, and for high-tension machines they are to be recommended. The Ferranti-Field system, usually designated as simple core-balance protection, is being used in some cases, but protection against faults between phases is essential for large sets. In the case of the mid-point gear the terminals must be protected by a special sheath, or a core-balance transformer can be provided. The size of the potential transformers used for the mid-point gear depends upon the sensitivity of the relays. Highly sensitive relays which will not require very large potential transformers are now available.

HYDRO-ELECTRIC RESOURCES OF THE SCOTTISH HIGHLANDS.

By Professor MAGNUS MACLEAN, D.Sc., LL.D., F.R.S.E., Member.

(*Lecture delivered at the* SUMMER MEETING OF THE INSTITUTION *at Glasgow,* 31*st May,* 1922.)

One of the most far-reaching effects of the recent Great War has been to bring the nation face to face with its own resources. For decades previously its chief concern had been the promotion of specialized industries in the large centres. Almost everything else was sacrificed to this national activity; and the lives of men were moulded to feed the fires and keep going in pitiless monotony the rattle of machinery, which was fast becoming an industrial Moloch. No doubt the age of coal and iron may have to be regarded as a necessary stage in the onward march or evolution of civilization. But we have only to visualize the effects as we know them, to realize how far a large proportion of the working classes have been side-tracked by this industrialism.

The wonderful thing is that we have hitherto been so blind with regard to our real assets. It is plain enough now that we have erred in two ways. On the one hand we have wasted most extravagantly many of our resources, and on the other hand we have almost entirely neglected others. To be economical was tantamount to being mean, for the more we wasted and destroyed the more it was thought we benefited the workman. Resources that could not compete with the great centralized industries, or ministered only to the æsthetic, the ethical, the moral or spiritual well-being of the population were more often quietly ignored. Only a feeble attempt was made to render them practically available.

In the midst of the great struggle we were forced by stern necessity to take stock of our resources in a way that the nation has never been called to employ before. As a result our eyes are now open to new possibilities and new potentialities. We think of agriculture and allotments, of afforestation, of man-power, of water-power, of the housing and health of the people, of transport, of education and many other things.

Of the various national resources to which the attention of the Government and of the people is now directed, water-power is dominant. Personally I am concerned with it not only as an industrial proposition but also as a means of elevating the national life, of restoring its man-power, of relieving the congestion in the large centres, of resettling the people on the land and of furnishing them with better houses, better food and clothing, and a more natural life in the country. In a word, I hold that the proper use of our water-power in the Scottish Highlands would go far to solve some of our pressing problems and promote comfort and contentment among large sections of the population. This healthy life of the country would react in a beneficial way upon the higher interest of the cities.

When we remember that the main sources of water-power are the rivers and lochs and waterfalls in the Highlands, we realize at once their value towards those ends. In the past for several generations the Highlands have been pouring their best manhood and womanhood into the cities and towns; and the glens and straths have been becoming more and more desolate. Much of the land has been going out of cultivation and, like the hills and the moors, was being given over to deer and sheep. The nation as a whole came to regard the Highlands more as a preserve for sport, or as a summer resort.

We think of those splendid regiments who have fought for us with such distinction on the fields of Flanders and in the uttermost parts of the earth, bringing victory to our cause—the cause of right and freedom. We do not wish this race—these hardy sons of the mountain—to die out through their land becoming desolate. We want to keep them on the soil as far as is consistent with their own well-being, not only as a bulwark of our freedom, but, in the future, more especially to rejuvenate the life of the nation by infusing new blood and fresh ardour into the cities.

Then we know that these hills so silent and so stable are admirably adapted for afforestation. Thousands of acres of trees have been cut down on their slopes during the war, and thousands of trees are still being removed to supply the necessities of industry; so that the land in this respect is becoming depleted. There is need to make use on a much larger scale than ever of the hills and moors that were once the great Caledonian Forest chosen by Nature for tree and shrub.

A little industry introduced here and there throughout the Highlands to supplement the local activities and at the same time to utilize more fully the local resources, is what is needed. For this industry water-power is immediately available and it is so distributed by Nature that there need be no congestion as in the large centres, but it may be easily apportioned to serve wide areas over the land.

Villages which would be miniature garden cities would thus begin to spring up as marts and centres for the rural districts; and the housing problem which is now so urgent could in these parts be solved by laying out these villages on new lines, and erecting cottages with gardens, not more than six or eight to the acre.

Hitherto the Highlands have been severely handicapped in the matter of industrial activity through not having a coal supply of their own on an adequate scale. Now that the coal shortage and dearness of fuel for power purposes is acutely felt elsewhere as well as in the North, it is all the more important to turn to the bountiful provision of Nature whereby we are no longer dependent entirely on coal for power, but

may have our own railways and machinery worked by a more simple and, in the Highlands at least, more readily available natural resource. The extent of the Highlands is 40 per cent of that of Scotland, and only 7 per cent of the population is within that area. Newlands has said: "It is in territory such as this that a keen discriminating intellect is developed, and that the brawn and muscle of the British race is bred and reared, and not in congested hives of industry, and if employment can be found for such a people in their own environment it is all to the nation's interest to provide it."

On the 6th June, 1919, I read a paper before this Institution in Aberdeen on water-power, and I then summarized the natural sources of energy, as tides, food, fuel, wind and rain. I referred more especially to the first Interim Report of the Water Power Resources Committee dealing with nine possible water-power schemes in the Highlands capable of giving 183 500 (continuous) electrical horse-power, and the average estimated cost per electrical horse-power at the power house was £38·5. Since that date the Committee have issued a second, a third, and a final Report in 1921. The final Report is a voluminous volume and gives details of 39 schemes in the Scottish Highlands which, if developed, would yield 189 000 kW (continuous).

No. of Table	No. of Schemes	Kilowatts (continuous)
2	12	112 190
3	3	8 290
4	8	16 470
5	9	6 655
6	3	38 700
7	3	5 680
8	1	1 120

In addition to these schemes there is the Lochaber Water-Power Act, 1921, which provides for the production of 23 000 kW (continuous). Alternative and modified schemes are given in different appendixes by well-known engineers, and a study of these is recommended to anyone specially interested. The Committee very correctly state: "Remoteness from populated districts may be a factor facilitating the prospects of developing a particular water-power site, since under such conditions there are usually fewer interests to be conciliated, and, in consequence, the expenditure on compensation and rebuilding is likely to be comparatively small. In this respect, the conditions in the Highlands of Scotland are very favourable for water-power developments. The population is sparse in most of the areas in which water-power resources are situated. Yet, owing to the character of the coast line and the position of the Caledonian Canal, no water-power site is far removed from a point from which ready access to the sea is obtainable. The majority of the schemes communicated to us by the Board of Agriculture for Scotland are relatively small, but we understand that in most cases they are contiguous to fishing centres or to railways where ready means of transport for manufactured articles can be obtained, and there is already in existence a local population from which labour could be obtained for industry.

"The Highlands are very sparsely populated and we understand that the generally prevailing low standard of comfort in the area is responsible for an abnormal amount of emigration which it is highly desirable to arrest. Generally speaking the land is poor and affords little promise of agricultural development, there are few minerals of value, and, apart from sheep rearing and what agriculture is practised, the population are dependent on the fishing industry, forestry and sport for a difficult existence. A main contributory factor to the emigration which takes place is the absence of social and domestic amenities. The development of water-power in the Highlands would tend to stop the tide of emigration, and would actually lead to immigration of labour from the Lowlands, and hence the growth of an industrial population would cause a demand for foodstuffs which would lead to an improvement in the pastoral agriculture of the adjoining areas."

The second Interim Report deals with the general nature of the machinery of control which is required in order that the water resources of Great Britain may be properly conserved and fully and systematically utilized for all purposes. The Committee say: "In the development of water-power both large and small, facilities must be given for private enterprise of different kinds as well as for public electricity supply. While there are localities where water-power will in the future be properly developed to assist the generation of electricity for public supply purposes, there will also be cases, especially in Scotland, where the geographical situation of the water-power will only permit of the full utilization if an industry is set up alongside, or in direct connection with the water-power station, e.g. the British Aluminium Company at Kinlochleven. In many cases the power to be developed may be small or remote from a public electricity supply system: in such cases private enterprise may be the only means of securing its development.

"The development of large water-power undertakings necessarily takes some years and during the constructional period capital is expended without any accruing revenue whatsoever. When once completed, however, the undertaking would be a valuable source of wealth, and it is important to remember that by far the largest portion of the total running costs is represented by interest and other charges upon the capital sunk in the undertaking. Private enterprise will need encouragement, especially in the Scottish Highlands, where the population is too sparse to allow an undertaking of this nature to be established through funds advanced by local authorities, to whom the large capital involved would be too great a burden to be practicable. It will, therefore, be necessary to assist some of the schemes out of national funds, the return on which should represent a sound investment for the State, and without which this valuable source of power would continue to be wasted."

I propose now to draw attention to some water-power schemes already in existence in the Scottish

Highlands and also to refer to some proposals that have materialized since 1919, when I read the paper to which I have referred.

The hydro-electric works at Foyers commenced operation in 1895, and the production of aluminium there was described in a paper* read by Mr. W. Murray Morrison before the Glasgow Local Section (now Scottish Centre) of this Institution on the 10th December, 1901, which paper should be referred to for details. The water is derived from the River Foyers which has a catchment area of upwards of 100 square miles. Two lochs have been joined together by dams and embankments so that the area is about three square miles, the storage being sufficient to give a continuous supply for about seven weeks. The head of water is 350 feet. Originally there were seven large Girard turbines built by Messrs. Escher, Wyss and Co., driving seven vertical direct-current low-pressure Oerlikon dynamos of 700 electrical horse-power each at 150 r.p.m. Mr. Morrison wrote to me quite recently: "The old plant is still doing very satisfactory duty, but some years ago two further units were added, being Pelton wheels by Escher, Wyss and Co., and generators by Dick, Kerr and Co.; also one smaller unit was added."

On the 14th November, 1911, a paper was read by Mr. Alfred Henry Roberts before the Institution of Civil Engineers on "The Loch Leven Water-Power Works," and on the same evening a paper on "The Hydro-Electric Plant in the British Aluminium Company's Factory at Kinlochleven," was read by Mr. Frederick Bolton Sonnenschein. These two papers and the discussion occupy 114 pages of the Proceedings and are well worth careful study by anyone interested in the subject. The company that obtained the Act of Parliament in 1901 was the Loch Leven Water & Electric Power Company, but the construction was deferred and in 1904 a revised scheme was submitted to Parliament and duly authorized. The factory work started in February 1909. The whole of the works are now the property of the British Aluminium Company. Mr. Roberts states the requisite features of a commercially successful water-power installation to be: (1) a large catchment area; (2) a heavy rainfall; (3) suitable sites for a storage reservoir, and for the construction of a dam; (4) a high fall to give a large head at the turbines; (5) suitable space for the construction of power house, factories and dwelling houses, at a low price for the land; (6) nearness to a large industrial centre—or to the open sea, if the power can be utilized on the spot for manufacturing purposes; and (7) suitable facilities for the provision of wharves, and protection for shipping in a natural or artificial harbour. A portion of Mr. Roberts's paper is devoted to prove that these advantages are all possessed in a remarkable degree by the Loch Leven water-power scheme. Mr. Sonnenschein's paper deals with the power plant and the generators.

Since the completion of the works as described in the above two papers important additions have been made. Mr. W. Murray Morrison, the General Manager of the British Aluminium Company, supplies me with the following information: "In the first place there has been an extension of the water-collecting area by 6·1 square miles, arising out of the inclusion of Loch Eilde Mor and Loch Eilde Beag, together with the streams running into them. A dam has been constructed at the lower end of the former, and connection has been established between it and the main reservoir behind the Blackwater Dam by means of a reinforced concrete pipe about 5 miles long. At about two-thirds the distance between Loch Eilde Mor and the Blackwater Reservoir a side intake was constructed for the purpose of taking in the flow from the stream Allt Coire Na Duibh, the pipe diameter to this point being 48 inches and between the side intake and the Blackwater Reservoir 54 inches. A discharge chamber was constructed at the outlet with measuring weir fitted with the requisite apparatus for enabling a continuous record to be kept of the flow.

"The work was carried out to the designs of Mr. C. S. Meik, under the direct supervision of the late Mr. Bryce Johnston. The contractors were Messrs. Balfour Beattie and Co., Mr. Pitcairn acting as their agent. It was commenced in the beginning of 1916 and was sufficiently completed by January 1918 to enable water to be taken in at the side stream intake. The work was fully completed and water was flowing through from Loch Eilde Mor by the end of July 1918. Owing to the extreme importance of increasing the output of aluminium during the war, the Government arranged for the supply of about 1 000 German prisoners of war to assist in carrying out the work.

"In order that the fullest use might be made of the additional water supply from the above source, it was decided that the main dam at the Blackwater Reservoir should be increased in height to the extent of 3 feet. This has the effect of providing additional accommodation for 260 million cubic feet of water, making a total of 3 820 million cubic feet, which is sufficient to maintain the whole of the plant in operation for a period of about three months.

"The plant as installed originally in the power house consisted of nine sets each of 2 000 kW capacity, which together with the auxiliary generating sets for traction and lighting gave a total plant capacity of 19 150 kW. An additonal set of 2 000 kW was installed in 1914, consisting of a turbine by Messrs. Escher, Wyss and Co., of the same design as the original plant except that it is fitted with deflectors to each of the nozzles in place of the by-pass arrangement for obviating any sudden increase in pressure in the pipes on the sharp reduction of the load. Further, the needles are operated by the governors by means of an oil pressure regulator. The direct-current generators are of similar type to the original plant and were supplied by Messrs. Dick, Kerr and Co.

"In view of the additional water available from Loch Eilde Mor, a further 2 000-kW generating set was ordered and installed in 1918. This consists of a turbine of the Pelton wheel type supplied by Messrs. James Gordon and Co. It differs from those supplied by Messrs. Escher, Wyss and Co. in that it is fitted with one nozzle only. The governor and needle gear is of the oil-operated type, and a deflector which is fitted to the nozzle comes into operation with sudden variations

* *Journal I.E.E.*, 1902, vol. 31, p. 400.

of load so as to prevent heavy increase in the pressure in the pipes, which would arise if the needle gear were arranged to close quickly. The generators are identical with those previously installed. The total plant capacity is now 23 150 kW for continuous running, with an overload capacity of 25 500 kW. Considerable extensions to the reduction furnace plant were made, and, in order to meet the increased demand for carbon electrodes arising out of the increase in the aluminium reduction plant, extensive additions have been made to the carbon factory ; not only did these enable the Company to maintain their own works in operation but they were at the request of the Government, during the war, called upon to supply a very large quantity of electrodes for shipment abroad to works under the control of the Allies.

"Arising out of the increase in output generally, and particularly out of the necessity of employing women during the war, the Company have had to carry out considerable extensions in the way of housing accommodation, inclusive of the erection of three hostels, each of which accommodates 100 persons, and is self-contained in that it has its own kitchen, dining and recreation room, baths, etc.

"In view of the very great importance during the war of maintaining the maximum output of aluminium, the Government decided to proceed with the long-talked-of road between Ballachulish and Kinlochleven, so as to afford further means of communication beyond that already existing by sea. The work was originally put in hand with the labour of conscientious objectors, but later these were replaced by German prisoners of war. The work was therefore interrupted by the Armistice, and has only been carried on slowly since then by the local road authorities. It is, however, now practically completed and has been opened for traffic.

"It is interesting to note that the maximum possible output of aluminium was maintained without interruption throughout the war, when it was, of course, of the utmost importance that the largest possible quantity should be placed at the disposal of the authorities.

"During the past 12 months the universal depression in the metal and most other industries has necessitated the temporary closing down of a considerable amount of the plant, but recently some of the plant was restarted and the works are now operating at nearly full load."

I shall now summarize two proposed hydro-electric schemes, namely, the Lochaber Power Scheme and the Grampian Power Scheme.

The catchment area of the Lochaber water-power scheme, promoted by the British Aluminium Company for the development of which an Act of Parliament was obtained last year, is 303 square miles. Taking the average rainfall as 73 inches this gives 1 056 million gallons per year per square mile, and therefore for the whole area 876 million gallons per day. The average head of water available near Fort William is 742 feet, so that the theoretical horse-power is 137 300. The Company estimates 72 000 to 75 000 horse-power (continuous) which gives as their estimated efficiency about 60 per cent, but they anticipate that 100 000 h.p. will be obtained in all but the drier years. Now, 1 h.p.-year is equivalent to 6 535 kWh and to 10 tons of coal. Thus the Lochaber water-power scheme would result in a saving of $\frac{3}{4}$ million to 1 million tons of coal per year. Of the total generated a minimum of 5 000 h.p. has been reserved under the terms of the Act for other industrial consumers. The proposal is to form a weir just below the confluence of the River Spey and the Markie Burn, about $2\frac{1}{2}$ miles to the westward of Laggan Bridge in Inverness-shire. During floods the level of the Spey at the point would be raised by some 30 feet, so that a small reservoir about 2 miles long and just under $\frac{1}{2}$ mile in its widest part will be formed. A great deal of discussion took place before the Select Committee of the House of Commons on this part of the scheme, as to its effect on the fishing of the Spey. The Spey Fishery Board wanted 100 million gallons a day as a minimum flow and refused an offer of 45 million by the promoters. The Committee by way of a compromise decided : (1) that the water of the Upper Spey above the upper intake is not to be abstracted up to a flow of 30 million gallons per day ; (2) that the Spey Fishery Board shall have the right to demand that in 12 days of the year (not necessarily consecutive) water shall not be abstracted until the natural flow of the river reaches 100 million gallons per day ; and (3) that the conduit at the intake of Loch Laggan shall be increased by 75 per cent. When the Committee met two days afterwards to adjust clauses it was intimated that the Spey Fishery Board after consideration preferred to have a flow of 40 million gallons per day all the year round on such days as the flow of the river allowed it.

The water so derived from the Spey is to be led through a conduit nearly 3 miles long to make a junction with the River Pattack near the point where it turns westward to flow into Loch Laggan, the difference of level being from 860 feet above ordnance datum to 840 feet. A dam is to be constructed on the River Spean about $3\frac{1}{2}$ miles from the outlet at Loch Laggan, with the result that the loch will be lengthened from 7 to $10\frac{1}{2}$ miles and this is to be called the Spean Reservoir. A tunnel $3\frac{3}{4}$ miles long connects the reservoir with Loch Treig, whose level is to be raised 36 feet or 1 foot lower than the top water level of Loch Laggan. The power house is situated on the banks of the River Lochy just above Fort William, and the tunnel connecting it with Loch Treig is to be no less than 15 miles in length. The waters of 14 streams are to be tapped on the way by vertical shafts varying in depth from 175 feet to 350 feet. A description with a map and a section appeared in the *Engineer* of 4th March, 1921, and for further details I would refer those interested to that article.

One of the most interesting paragraphs in the above-mentioned article is that referring to the tunnel from Loch Treig : "Loch Treig, which is rather over 5 miles long and $\frac{5}{8}$ mile wide in its widest part, has a normal level at the present time of 783 feet above ordnance datum, that is to say 37 feet below the top water level of Loch Laggan. It is proposed, however, to raise its level to 819 feet above ordnance datum, or 1 foot below the top level of Loch Laggan, by means of a dam. It will thus be observed that the water coming down from the Rivers Spey and Mashie, the Markie Burn,

Loch Laggan, and the Spean Reservoir, will gravitate into Loch Treig, which will, in fact, act as a fore bay of the power house, for the water from it will be continuously under pressure until it issues from the turbines. It is a deep loch having a maximum depth of some 436 feet, and one of the most interesting features of the whole undertaking is that, by means of a tunnel, it is proposed to place the invert of the outlet at 680 feet above ordnance datum, or no less than 139 feet below the raised top water level of the Loch. At present no details of how the work of driving the tunnel into the Loch is to be carried out have been made public, but it will be an interesting operation."

Mr. Morrison in giving evidence before the Select Committee stated that it was the policy of the Company to employ local labour as far as possible, and they had supplied satisfactory accommodation for their workers. He said : " If the present scheme is sanctioned the Company will be able to employ nearly 3 000 additional hands. Last year they paid £170 000 in wages at their factories at Foyers and Kinlochleven. Of the employees 80 per cent are Highlanders and Islanders. The construction work of the new scheme, if authorized, will occupy about 5 years, and during that time will provide employment for several thousand men."

The Grampian Water Power Scheme of 1921, which conflicted with the Lochaber Scheme, especially as to the utilization of the water of Loch Pattack, was withdrawn. This year a modified scheme has been passed recently by a Select Committee of the House of Commons. The promoters are the Hydro-Electric Development Company and they aim at supplying electricity for all purposes in the counties of Perth, Kinross and Forfar, and the parishes of Kingussie, Insh, Laggan, in Inverness-shire ; Lismore and Appin in Argyllshire ; and Buchanan, Drymen, Killearn, Balfron, Kippen, Fintry and Gargunnock in Stirlingshire. Over 50 lochs, rivers and streams are involved in the scheme, but the chief ones are Lochs Ericht, Rannoch and Garry, the River Garry, Loch-an-Seilich, Loch-an-Ruin, the Truim, Bruar River and the Mhairc Water.

The catchment area is 417 square miles and the proposed four power houses can give out 56 000 h.p. continuously, as follows : Tummel 17 400, Garry River 7 500, Bruar River 4 200, and Loch Rannoch 26 900. The power house at Loch Rannoch is to be supplied by a tunnel from Loch Ericht which is to be raised in level by 37 feet. The storage capacity of Loch Ericht will be 80 000 million gallons, of Loch Garry 410 million cubic feet, and of Loch Rannoch 1 600 million cubic feet or 10 000 million gallons. The first part of the scheme, beginning with the Tummel, would cost £2 603 000, and the whole scheme 4½ million pounds. It was stated in evidence that on the completion of the first stage, if a sale of 170 million kWh per annum were assumed, the cost per unit would be ⅝d.

There was considerable discussion about the financial arrangements, and Mr. Briggs, M.P., a member of the Select Committee, expressed the view that the project was of a highly speculative nature and one in which Government money should not be invested. On the 11th May he asked the Chancellor of the Exchequer in the House of Commons : " If he is aware that the promoters of the Grampian Electric Supply Bill have received a letter, dated 20th April, 1922, from the Secretary of the Trades Facilities Act Committee, stating that, subject to the approval of the Electricity Commissioners, the Committee would be prepared to recommend a guarantee of both Capital and Interest of the Debenture issue of the Company equal in amount to the Ordinary Share Capital of the Company, and if he is satisfied that the Commercial future of this Company warrants the use of public money to guarantee Capital and Interest to such a proportion of Debenture issue."

The Chancellor of the Exchequer replied that he proposed to be guided in the guarantees given under the Act solely by the advice of the Trade Facilities Advisory Committee, which consists of three business men of great experience and ability. At the third reading of the Bill on 23rd May there was a motion for its rejection which was defeated by 185 votes to 78.

The City of Dundee has increasing demands on its electrical station, and the Corporation had in view a possibility of buying electricity in bulk from the Grampian Company provided an adequate supply at a low cost could be guaranteed. Failing satisfactory guarantees as to the amount and continuity of the supply of current by the Company, Dundee had in contemplation a scheme of their own, but as they included the utilization of Lochs Ericht and Rannoch, now granted to the Grampian Company, I need not give details. Dundee withdrew its opposition to the Grampian Scheme, provided that the Company undertook not to run their cable through Dundee, and that permission for electrified construction should be limited to main-line electrification of railways only. Also, by a majority the Dundee Committee decided to enter into an arrangement with the Company if the price of electricity be reduced to £3 per annum per kilowatt of maximum demand, and ½d. per kilowatt-hour, provided that the Company paid the standing charges, plus a fixed annual rental of £5 000 in respect of the Corporation's electrical station, and provided also that the other conditions of the agreement should be satisfactorily adjusted between the Corporation and the Company.

The Electrical Engineer of Dundee has recently written me to the effect that : " As regards the supply of power to Dundee by the Grampian Company, as they have had to admit that they are unable to compete with the present thermal system in Dundee the only possible hope is a combination of the hydro-electric stations with my present steam stations. Such a combination is able to show, on paper at any rate, a possible small saving in years to come so far as Dundee is concerned. Future saving, however, depends so much upon the possible cost of coal that it is very difficult for the Council to decide to give up control of its own generating station. There is a section who believe that the cost of coal will go up, and in any case labour troubles will never cease, so there is an advantage in favour of water power with its comparative independence of labour disputes. In short, Dundee is prepared to buy as soon as anyone has current to sell—at a price."

I shall now describe two small water-power schemes making use of the water of streams without reservoir or batteries. The electricity generated is utilized in

lighting and heating mansion houses and driving electric motors for farming purposes.

The first is at Inshes. This hydro-electric installation is very interesting as it shows the possibility of harnessing the water power of small streams in the North of Scotland, and there are hundreds of such streams. The scheme was prepared and carried out by Mr. E. J. Williams, Scottish Manager for Messrs. Edmundson's Electricity Corporation. The estate concerned lies $2\frac{1}{2}$ miles to the south-west of Inverness. There the River Millburn, about $2\frac{1}{2}$ miles in length, owes its present name to the fact that in quite recent times meal mills driven by water power were quite common in the Highlands and there were no less than six such mills on this stream. The total output of these water-power meal mills, four of them of the overshot type, was 40 h.p. The average flow of the river is about 120 cubic feet per minute and the minimum within recent years 90 cubic feet per minute, though during last year's drought it dropped to 50 cubic feet.

At the power house there is installed a "Turgo" impulse turbine by Messrs. Gilbert Gilkes & Co., of Kendal. The gross head of water is 320 feet. It was found that with a head of 310 feet and a flow of 96 cubic feet per minute the output of the turbine was 34 h.p., and the overall efficiency (including 9·7 feet as the loss due to friction head) was 60 per cent. When the flow was 224 cubic feet per minute the output was 88·3 h.p. and the overall efficiency (including 53 feet as the loss due to friction head) was 67·4 per cent. Coupled to either side of the turbine is a compound-wound generator of 22 kW capacity. The installation in Inshes House, 1 000 yards distant, consists of 150 30-watt lamps for lighting, a few heaters, a hot-plate in the dining room, and a washing machine and irons in the laundry. The power house is connected to the Inverness town network by a pole line $1\frac{1}{4}$ miles in length. Mr. Williams, writing in the *Electrical Review* in December 1920 two months after starting, said: "The supply from the scheme has enabled the Inverness local electricity works to dispense with a Sunday morning shift of two men, and it has also reduced the running hours of the steam plant by at least one hour per day, it being possible to start up half an hour later in the morning, and shut down at least half an hour earlier at night." Writing to me quite lately he says: "With regard to the Inshes scheme, I may say that now there are five farms and seven large houses connected to it, and that in each of the farms beside the lighting there are motors. The lines are at present being extended to the village of Culcabok where it is intended to give the villagers a supply at a fixed charge per lamp per annum. The surplus current which is fed into the town network is quite as much as estimated, and for the year now just completed this amounted to 95 000 units. The current used locally by the farms amounted to a further 14 000 units. The scheme has in every way come up to expectation, and has aroused a good deal of interest in the North."

Messrs. Allan Arthur and Ure, Glasgow, have supplied me with information about a water-power plant which they designed and installed during 1921 near the head of one of the sea lochs in Argyllshire. The catchment area of the stream from which the power is derived is about 2 square miles, with hills rising on either side to over 3 000 ft. It was found that the minimum flow after 6 weeks' drought was 50 cubic feet of water per minute, and the maximum 20 times this. Hence it was decided not to build a reservoir but to build a substantial concrete weir across the stream at a level 290 feet above the turbine house, which would act as an intake. The pipe line, which is about 2 000 feet long, is carried underground to the turbine house situated on the bank of the stream and at a distance of about 50 yards from the dwelling houses, to which the cables are led underground.

The turbine, which is of Messrs. Gilbert Gilkes and Co.'s make, is capable of giving 33 b.h.p. or 22 kW at full load at about 650 r.p.m. and of passing 85 cubic feet per minute. The dynamo which is direct coupled to, and on the same bedplate as, the turbine is of Messrs. Horace Green and Co.'s make, compound-wound and designed to give 85 amperes and 270 volts at 650 r.p.m. The plant runs continuously night and day, and no batteries are installed. In the mansion house there are over 100 lamps and plugs for lighting, while in the kitchen there is a cooking range consisting of two ovens, hot cupboard, grill and six boiling rings, the total loading being 13·6 kW. The hot water supply for the house is obtained from an electrically heated 45-gallon tank. Four electrical elements are fitted in this, each loaded to $1\frac{1}{2}$ kW, the temperature being automatically controlled at any setting desired, by means of a thermostat.

The whole scheme is designed for lighting, cooking, hot water heating, heating and drying by electricity, and thus 50 to 60 tons of coal are saved annually, as well as the expense and inconvenience of carting it for many miles to the house. Should additional heating be required, wood is burned in the fireplace. On the estate there is an abundance of wood which is cut up by a 36-inch saw driven by a 12-h.p. motor at times of light load on the turbine. The installation has been running with complete satisfaction for 18 months, the only expense being a few pounds for lubricating oil and replaced elements.

There are scores of similar Highland streams running to waste through sparsely inhabited glens and straths, which could be utilized for industrial and other useful purposes at comparatively small expense. The rainfall varies at different parts of the Highlands, but it may be taken that every square mile of catchment area, even in summer, will give an average flow of 180 cubic feet per minute or one electrical horse-power at 75 per cent efficiency for every 3·9 feet of fall. Thus there exists in the Highlands in our lochs and rivers considerably over half a million potential horse-power which should at once be utilized in establishing suitable industries in the places where the power is available.

We are now at a point of departure in our whole industrial system. The old order, black and barbaric in many features, is yielding place to new methods. The handicaps of the present time are so ominous and clog the machinery of life so much that the spirit of man struggles to be free, and in so struggling the mind of man finds out many inventions. We are thus in

the midst of readjustments which herald the dawn of a new era—a better time for the world—and it is given to us to be pioneers in the process. We cannot forget that for all practicable purposes, light, heat and power are coming more and more to be comprehended in the word "Electricity," and, as our coal resources are being depleted, we must rely for its production in the future to a far greater extent on oil and water-power, and other at present undeveloped agencies. The oil and the water-power are already within our grasp, waiting to be used.

The practical part is a problem of intense interest to us as electrical engineers, but beyond the industrial and commercial I think we may all claim to have some interest in the moral and spiritual aspects of the question. At the best, getting coal in the bowels of the earth in the dark, damp, cramped and often nauseous conditions obtaining there, is not exactly an ideal way of making men. It is barbarous and unnatural, though now so utterly essential to us. In the future—and may it be the near future—I fancy people will wonder at the black age, at the black hands and faces and clothing of men and boys emerging from the pits. If these conditions fail to develop the best in man, if they lead, as we suspect they do, to a moral obliquity or even moral blindness, can we wonder? Therefore, in developing the resources of Nature, such as oil, water-power and electricity, we are helping to clean and brighten the lives of thousands of men, and to deliver them from the grinding care and the black misery of the nether regions, thus raising them to a higher level of health and happiness and a higher ideal of manhood.

PROCEEDINGS OF THE INSTITUTION.

SPECIAL GENERAL MEETING OF CORPORATE MEMBERS AND ASSOCIATES, 23 MARCH, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 5.45 p.m.

The Notice convening the Meeting was taken as read.

The President: This Meeting has been called for the purpose of passing a formal resolution. After moving the resolution, I shall ask the Honorary Treasurer to second it and to give any explanation that he desires. The resolution is required for the purpose of transferring to the Chartered Institution the remainder of the liabilities of the old Institution in respect of the mortgages to the Alliance Assurance Company on the Institution building and the property in Tothill-street, Westminster. I move the following resolution :—

"This Meeting hereby authorizes the Council to borrow from the Alliance Assurance Company Ltd. the sum of £16 340 7s. 8d. by way of Mortgage on the Institution Building on the Thames Embankment in substitution for the Mortgage made by the Institution of Electrical Engineers (under the Companies Act 1862–1867) to the said Alliance Assurance Company upon which the same amount is now due. The said Mortgage to be in the form of the draft Deed already prepared and now submitted to this Meeting and initialled by the Chairman.

"And also to borrow from the said Alliance Assurance Company Ltd. the sum of £7 500 by way of Mortgage on the freehold and leasehold property of the Institution in Tothill-street, Westminster, in substitution for the Mortgage made by the Institution of Electrical Engineers (under the Companies Act 1862–1867) to the said Alliance Assurance Company upon which the same amount is now due. The said Mortgage to be in the form of the draft Deed already prepared and now submitted to this Meeting and initialled by the Chairman."

Sir James Devonshire (Honorary Treasurer): I beg to second the resolution. I should like to say that the original loan on the Institution building amounted to £26 000. That amount had been reduced by obligatory repayments until there was due on the 1st January last, as will be seen from the Accounts, £16 831 19s. 11d. We repaid in January last £491 12s. 3d., leaving a balance now due of £16 340 7s. 8d. That is the sum referred to in the first clause of the resolution. With regard to the Tothill-street property, the original loan was for £11 500, and that sum had been reduced by repayments so that on the 1st January last there was due, as shown in the Institution's Accounts, £7 500. A sum of £3 000 will be paid off that amount this week-end. I beg formally to second the resolution.

The President: Does any member desire to ask any question? If not, I shall put the resolution.

The resolution was then put, and declared by the President to be carried unanimously.

The meeting then terminated.

SPECIAL GENERAL MEETING OF CORPORATE MEMBERS, 23 MARCH, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The President: First of all I would remind those present that Members and Associate Members only may vote at this Meeting. I will ask your permission to take as read the Notice convening the Meeting. (This was agreed to.) The object of this Meeting is to approve Bye-laws for the Chartered Institution, the Charter imposing on the Institution the duty of preparing Bye-laws. I shall refer in a very few words to these Bye-laws. According to the Charter these had to be prepared by the 15th February, but notwithstanding the very hard work done by a special Committee, of which Mr. Atkinson was Chairman, and in spite of the fact that the Council disposed of the business at two meetings only, we could not be ready by the 15th February. Consequently, with the sanction of the Privy Council the date was extended to the 15th April, and we want to make sure of getting these Bye-laws approved by that date. The Bye-laws follow very closely the Articles of Association of the old Institution, which were adopted by Special Resolution on the 30th May, 1910. They were altered by Special Resolution on the 15th June, 1916, the 14th June, 1917, and the 17th December, 1920. The alterations made in 1916 related to subjects of a country at war with His Majesty being disqualified for membership. The alterations made in 1917 enabled votes at Meetings to be given by proxy. The alterations made in 1920 were to increase the subscriptions. The old Articles have been found in practice to work most satisfactorily, and very few alterations in them are now proposed.

The explanatory memorandum which has been circulated sets out all the important ones, the others being minor alterations made necessary by the change from the old "company" body to the chartered body. The resolution which I now move is as follows: "That the Bye-laws submitted to a Special General Meeting of the Corporate Members of the Institution of Electrical Engineers, in pursuance of the Charter, held on the 23rd March, 1922, of which a printed copy has for the purpose of identification been signed by the Chairman of such Meeting, be and are hereby made and approved."

Mr. Ll. B. Atkinson: In the first place, I should like to say a word of thanks on behalf of the Committee, of which I have the honour to be Chairman, to many of our members for the trouble they took in sending in suggestions for the new Bye-laws, and also to quite a number of members, not so large as the first category, who took the trouble to go through them in great detail and make certain suggestions as to the wording when they were in draft. I am sure all those who were on the Committee will agree with me that we derived very great assistance from that outside help. In most cases the suggestions were such that the Committee were able to embody them in the Bye-laws. Taking the explanatory memorandum which most of you have in your hands, Bye-law 9 deals with abbreviated titles and description of Corporate Membership. The first part of that Bye-law is a repetition of the old Bye-law, setting out the use of the initials M.I.E.E., and so on. I will only draw your attention to one alteration which is an important one and which is in the Charter, namely, that the members of the Institution are entitled to the exclusive use of these terms. We made a special point of getting that word into the Charter, because previously it had been stated by all kinds of people who put these letters after their names that they were not describing themselves as members of the Institution of Electrical Engineers but, for instance, as members of the Institution of Elocutionary Experts, and the Council were placed in a difficulty in suppressing this unauthorized use of our initials. The Charter, which gives us this exclusive right, is prima facie evidence that we are in a position to stop anybody who does that in future, and that nobody has any right to attach these letters to his name but members of the Institution.

In the second part of the Bye-law the statement is made that "Corporate Members of the Institution who in the Charter are accorded the right of calling themselves members of the Chartered Institution of Electrical Engineers, shall, if they are Honorary Members or Associate Members, attach to that designation words indicating the class of membership to which they belong respectively, so that Corporate Members shall respectively be described," and then the description is set out in full. Some of our members have asked whether it would not have been better if we had arranged to get into the Charter the term "Chartered Electrical Engineer." In many ways it would have been much shorter and less cumbersome, and the Council did, in fact, seek to get those words inserted, but the Privy Council told us that they were not prepared to give in the Charter the right to use those words. We cited the case of the Chartered Accountants and others, but the reply was to this effect: "Yes, we allowed it, but it was a mistake which we shall not repeat, because as a matter of fact none of the members of these Associations or Institutions is in possession of a Charter. The Charter is given to the body as a whole, and in fact the correct designation is that they are members of a chartered body." So that the example which I have just mentioned will not be repeated with the permission of the Privy Council.

I pass next to Bye-law 11, Honorary Members. The old Article was worded in a way which enabled us to elect as Honorary Members at least two different classes of distinguished persons, one who was distinguished for his work in electrical science or engineering, and, secondly, a distinguished person whom we desired to honour either for services rendered or whose association was of benefit to the Institution. The old Bye-law rather mixed up these two groups, and as it was felt that an Honorary Member should in the main be a person who was distinguished for his work in electrical science or engineering, a limit of three was placed on the second category.

I next pass on to Bye-law 41, which deals with the question of expulsion. This Bye-law makes the Council, after all due inquiries similar to those provided in the old Articles, the authority on all questions of expulsion from membership, subject to a right of final appeal from the Council to a Committee of three Past Presidents nominated by the President. For the benefit of those who do not remember certain incidents that have occurred in the past over the question of the expulsion of members let me point out what happened. The old Articles provided that no member could be expelled without a resolution in General Meeting. Now where did that lead us? If this room were packed to its fullest capacity it would hold only about 500 persons out of the 7 000 Corporate Members and Associates of the Institution who have voting powers. From the very nature of the case, when some charge is being made against a member, there are very great difficulties in the Council issuing any detailed statement to the members on the question of what the expulsion is due to, quite apart from the difficulty that libel actions may arise. In any case it is an *ex-parte* statement. So we finally arrive at the conclusion that the only thing to do is to consider the whole question at a meeting and to rely on that meeting to settle it. As I have pointed out, that meeting represents only a very small part of the Institution, and it is quite easy in such cases to have a more or less packed meeting on behalf of the member whose conduct is under discussion. We then reach this position, that the Council must obtain proxies in advance, which, as I have already explained, will be in the nature of a blank cheque because the Council cannot put all the facts before the whole body of the members, or if they do they are only the facts of one side. The situation which then arises is that the Council is in this position: it puts the case to a meeting which it may know in advance to be a packed meeting, or it goes there with its full proxy powers, obtained before the defendant, if I may

so call him, has had an opportunity of stating his case. It is quite clear that such a procedure is not only unwieldy but may lead to very serious results. Consequently the Council adopted the view—having had the experience—that it was much better to regard the matter from this standpoint. As a rule these cases are not cases in which the Council is the prosecutor, if I may use that term. They arise because a certain number of members—I think it is ten—make a representation to the Council that they think somebody's conduct should be investigated. The Council, therefore, is in fact a Court before whom the people who make the allegation and the person whose conduct is under discussion come, and the whole matter is thrashed out. The Council, we believe and maintain, is an entirely unbiased body which hears both sides and has to arrive at some decision. It is suggested that the Council's decision should not be the final one. The Council is a Court subject to a right of appeal to three Past Presidents nominated by the President. I have no doubt that the Past Presidents selected would be those who were not active on the Council at the time, so that they are men independent of the Council, and who would be nominated by the President. The only flaw in that method, it has been suggested, is the fact that the President, who is one of the Council, is the nominating party. Going back again to the point that the Council is really a Court and not the prosecutor, I think that objection fails. Presidents of Institutions like this Institution do not get to that position unless thay are people whose character and judgment can be relied upon. If they were not, they would be found out long before they arrived at the position of President of the Institution. By the time a man is President of the Institution, I have no hesitation in saying, he is a man whose character is such that he does not look out for packed Appeal Courts in order to decide matters which are of importance to the Institution. The Council holds the view that the proper course to adopt is as set out in the new Bye-law, that the Council should hear these cases and go thoroughly into them, and that if the party is aggrieved with the decision he shall have a right of appeal to a Court composed of some of these Past Presidents, all of them men of experience and all of them men in whom the Institution has confidence.

I now come to Bye-laws 44 to 51, which refer to the Council. The principal changes we have made are these. A system has been in force for some years under which a certain fixed number of vacancies in the offices of Vice-President and Ordinary Member of Council must be created each year on the Council. This occasionally resulted in members having to retire from the Council before they had served three years, and it did not appear to lead to any particular result. If, however, we have a definite retirement from all offices at the expiration of three years, as is proposed, we get a definite period for which a man comes on the Council. His experience is definitely made use of, and nobody has the feeling that, when he has just started on some difficult work, by the operation of a ballot for the purpose of creating a definite number of vacancies he may be retired in the middle of his work and, in fact, the Council may be put to grave inconvenience by having all its plans and Committees upset. The Honorary Treasurer will not be eligible to serve more than three years in succession, and will continue, as in the past, to retire each year and to be re-eligible subject to the foregoing three years' rule. Provision has been made for an Associate to be eligible for this office. Bye-law 48 replaces the three Associate Members and three Associates serving on the Council by four Associate Members and two Associates, the point being that the number of Associate Members has increased very largely relatively to the Associates. Bye-law 49 provides that the Council shall nominate only for the exact number of vacancies. The reason for that is two-fold. First of all, if the general body of the members are not satisfied they may make additional nominations, and they have freely made them in the past few years. Experience has shown that it is difficult to get men to stand for the Council on a Council nomination when they feel that even the Council themselves who have nominated them cannot vote for all of them; in other words that they are only put up to see if they can get in, when even those who are nominating them are not in a position fully to support them. Then it was necessary under the old Article that the Council's nominations should include the names of at least three persons, of whom two should be Members, who had not previously served on the Council in any capacity. The obligation as to their being full Members has been omitted, as it proved an unnecessary and useless complication. Bye-law 50 refers to nominations by the general body of members for election to the Council. The old rule provided that only full Members were qualified to make such nominations. The privilege of nominating Associate Members for election to the Council has been extended to Associate Members, and it will also be possible for Members and Associate Members to join together in the nomination of an Associate Member if they wish to, and I shall propose a little alteration to the wording of the printed memorandum in order to carry that into effect.

I think that I have dealt now with practically all the important points about the Council. The remaining items arise in connection with two or three alterations that have arisen since the proposals were printed. I will deal with those now; there are only two of importance. I have just referred to Bye-law 50. In the circulated draft and in the actual proof of the Bye-laws it reads "Subject to and in accordance with the foregoing provisions, any ten Associate Members (but not more than ten) may nominate any qualified Associate Member to fill a vacancy as Ordinary Member of Council." We propose to alter that to read "Any ten Members or Associate Members (but not more than ten) may nominate any qualified Associate Member," that is to say it need not be entirely Members or entirely Associate Members, it may be a mixture of them. You may wonder why the words "but not more than ten" are put in. The reason is this, that under the old Bye-laws some nominees got 10 members to nominate them, that being the minimum, and some got 50. In that way the balloting paper was covered with names and, further, gave the impression that one

of the men was more highly thought of than the other by Members of the Institution. That was never intended. The Bye-law was simply intended to show that there was a sufficient number of Members who wished to nominate somebody. The other alteration that is suggested in the draft Bye-laws is in Bye-law 88: "The quorum at any Annual or Special General Meeting shall be five." That was the old rule and it was printed in the draft. But it has been suggested that in view of the fact that seven are required for a quorum on the Council it was rather ridiculous to make five a quorum for a Meeting of the whole Institution, and it is suggested that that number should be increased to twelve. With these remarks I formally second the resolution which the President has already moved.

The President: The resolution has been proposed and seconded. I will now ask if any member desires to make any observation on it.

Mr. F. W. Purse, Prof. S. P. Smith, Mr. C. Le Maistre, Mr. P. M. Baker, and **Mr. F. C. Raphael** then spoke, and **The President** and **Mr. Atkinson** having answered the questions asked, the Resolution was put to the Meeting and declared by the President to be carried unanimously.

681ST ORDINARY MEETING, 23 MARCH, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6.45 p.m.

The minutes of the Ordinary Meeting of the 16th March, 1922, were taken as read and were confirmed and signed.

Messrs. H. W. Couzens and J. T. Haynes were appointed scrutineers of the ballot for the election and transfer of members and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Member.

Jefferyes, George Charles.

Associate Members.

Creasy, Leonard Alfred.
Farrant, John Alfred P.
Field, Harold.
Finlay, George.
Fisher, William David.
Hart, Sidney.
Mounsdon, Cecil Frederick.
Nicholson, John Hedley.
Orringe, Joseph.
Rayner-Smith, Percy.
Robinson, Frederick William.
Trusler, William Jaffrey.

Graduates.

Andrews, Harold Arthur.
Brazier, Cyril James H.
Chapman, Sydney Ronald, B.Sc.
Elliott, Sydney Rayleigh.
Freeth, Lancelot Gerhard.
Holeman, Charles Herbert.
Honour, Cyril.
Jones, Walter Ernest.
King, William Houston
Lee, Ernest.
McAteer, Desmond O'Boyce T.
McGrath, Thomas.
Moscrip, William Roswell.
Retallack, Frank Vyvyan.
Salter, William Seabrook.
Whitehouse, Alfred Edward.

Students.

Abbey, Harold Edward.
Allpress, Hugh Stennett.
Ardern, Charles.
Arnold, Morris Hadrian.
Bader, Ernest, Lieut., R.E.
Bainton, Arthur Leslie M.
Bann, Reginald James.
Bennett, Charles Henry J.
Boyd, William John.
Bramwell, Eric Benjamin.
Bull, George Geoffrey.
Butterley, Archibald Donald.
Caldecott, Edward Douglas.
Campbell, Archibald Stewart.

Students—continued.

Castellain, Alfred.
Collard, Herbert William.
Creasey, Robert Leslie.
Davies, Ivor.
Deas, James Leil.
Elsden, Leonard Guy.
Fairlie, John Adams.
Früs, Stanley John.
Gahan, Douglas Gordon.
Gamble, George Mackley.
Gittins, William Minto.
Graham, Alexander.
Hall, Charles Henry.
Henzell, Charles Peregrine.
Hopkinson, Harlow.
Hunt, Reginald Percy.
Irving, Leslie John.
Isola, Augustus W.
Jackson, Thomas William.
Jennings, Joseph Keith.
Jones, John Cyril.
Keay, Edmund McLaren.
Kilshaw, John Booth.
Lambert, George Wrake.
Latham, Ashton.
Laverack, Dennis Arthur.
Lockton, Cedric Phillips.
Macdonald, Hector.
Macdonald, William Francis.
McEwan, John William.
McLellan, Douglas Hay.
Manning, Clifford B.
Marshall, George Norman.
Mathias, Stewart.
Maxwell, Gilbert Grierson.
Mumford, Albert Henry.
Nicol, Arthur Edward.
Palmer, Edmund William.
Pistorius, Leo Henry.
Pratt, Alfred Stewart R.
Richards, Dudley John E.
Rigby, Ivor.
Sammons, George Handscomb.
Sanderson, Donald Hector S.
Sparks, Harry Charles.
Stern, Maurice.
Stride, Harry Sydney.
Taylor, Frank Warburton.
Telfer, Frank Phillips G.
Turner, Walter Frederick.
Tweed, Cyril John F.
Tyacke, John Arthur.
Tyler, Thomas John.
Walmsley, Thomas.
Walton, William Francis J.
Willey, John Matthew.
Winder, Herbert Edward.
Womphrey, Edward Roger.

Associate.

Fladgate, William Francis, M.V.O., J.P.

TRANSFERS.

Associate Member to Member.

Bell, William.
Clothier, Thomas Dawson.
Crompton, Charles, Capt., O.B.E., R.E.(T.).
Fraser, Andrew.
Ridd, Percy John.
Spary, Percy George.
Whitehead, James.

Graduate to Associate Member.

Andersen, Reginald Charles.
Deshpande, Shankar Balevant, B.A.
Kill, Ernest Frederick.
Mowdawalla, Framroze Nusserwanji, M.A., B.Sc.
Rao, Pappu Subba, B.A.
Stokes, William Gordon.

Student to Associate Member.

Braathen, Emil.
Fisher, John Jacob.
Jones, Walter John.
Lee, John Harsant, M.C.

Student to Graduate.

Brooke, Harold.
Duke, George Edward.
Emsley, Frank.
Farrell, James Fraser E.
Garner, Richard Hough.
Hopwood, Robert Agar.
Moore, Robert James.
Newland, Ernest William J.
Shaw, Cecil Graham, M.C.
Slater, Joseph Thomas L.
Tyrrell, Charles Frederick.
Young, Henry Judd.

The discussion on the Draft B.E.S.A. Specifications for Motor Starters, adjourned from the 2nd March, 1922, was continued, and the meeting terminated at 7.55 p.m.

682ND ORDINARY MEETING, 30 MARCH, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 23rd March, 1922, were taken as read and were confirmed and signed.

A paper by Mr. R. Borlase Matthews, Member, entitled "Electro-Farming, or the Applications of Electricity to Agriculture" (see page 725), was read and discussed, and the discussion was adjourned to the Ordinary Meeting to be held on the 6th April, 1922.

The meeting terminated at 8.5 p.m.

21ST MEETING OF THE WIRELESS SECTION, 5 APRIL, 1922.

(Held in the Institution Lecture Theatre.)

Professor G. W. O. Howe, D.Sc., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting of the Wireless Section held on the 1st March, 1922, were taken as read and were confirmed and signed.

A paper by Major J. H. Whittaker-Swinton, R.E. (T.F.), Associate Member, entitled "The Provision of Power for Wireless Telegraphy" (see page 845), was read and discussed, and the meeting terminated at 7.55 p.m.

683RD ORDINARY MEETING, 6 APRIL, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 30th March, 1922, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

The following list of donors to the Benevolent Fund was taken as read and the thanks of the meeting were accorded to the donors.

Benevolent Fund: D. Adams, A. N. Aikman, T. R. Alexander, The Air Ministry (Wireless Section, Directorate of Research), P. F. Allan, C. Ardern, L. Armitage, H. S. E. Austin, E. Bader, W. Baird, C. J. Baker, A. L. Beak, Major B. Binyon, O.B.E., Brig.-Gen. W. Baker Brown, C.B., R.E., S. Banerji, R. D. Bangay, N. H. Barker, A. S. Barnes, C. R. Barry, H. W. W. Bean, J. S. Bean, J. R. Bedford, J. C. Beed, S. Beeton, D. E. Bell, S. F. Bickell, G. S. Blake, R. F. P. Blennerhassett, R. S. H. Boulding, B.Sc., O.B.E., J. R. J. Bowden, C. Brazier, J. A. Bromley, J. A. Broughall, R. P. Brousson, F. W. Browell, J. S. Brown, W. H. Brownjohn, G. L. Bruce, Captain S. Brydon, M.Sc., A. T. Bullen, P. G. H. Burbridge, W. E. Burnand, A. Campbell, R. H. Campion, A. F. Carter, F. L. Castle, J. K. Catterson-Smith, H. C. Channon, E. N. Christmas, L. F. Christy, W. L. Chubb, R. C. Clinker, W. C. Clinton, H. W. Clothier, N. Clough, W. R. Cooper, M.A., P. R. Coursey, B.Sc., G. L. Coventon, The Hon. E. H. Cozens-Hardy, Col. C. G. G. Crawley, F. W. Crawter, E. Cunningham, B. Davies, F. E. Davies, J. Davies, G. B. Dent, Sir J. Devonshire, K.B.E., T. J. Digby, R. Dixon, A. Douglas, H. M. Dowsett, B. M. Drake, Dr. C. V. Drysdale, W. H. Duncan, A. H. Dykes, Dr. W. H. Eccles, F.R.S., Major K. Edgcumbe, F. S. Edwards, C. F. Elwell, M. Esskildsen, S. E. Fedden, H. Field, W. D. Fisher, Dr. J. A. Fleming, F.R.S., Prof. C. L. Fortescue, W. Foulds, L. F. Frogarty, J. W. Fyfe, H. P. Gaze, F. J. Gerrard, V. W. Gill, Sir R. T. Glazebrook, K.C.B., F.R.S., T. E. Goldup, R. P. Howgrave Graham, A. Gray, J. Hunter Gray, K.C., F. Y. Grepe, F. E. Gripper, C. H. Grover, C. W. Gwyther, C. J. W. Hanson, R. Hardy, F. H. Harris, G. E. Harrison,

Haydn T. Harrison, C. C. Hawkins, W. C. C. Hawtayne, W. J. Head, Sir J. B. Henderson, D.Sc., E. A. Hick, J. S. Highfield, A. J. Hodgson, H. Holman, Prof. G. W. O. Howe, D.Sc., P. Huggins, W. S. Hunt, C. G. Huntley, C. G. Hyde, Admiral Sir H. B. Jackson, G.C.B., K.C.V.O., F.R.S., W. G. C. Jackson, H. H. Jacques, R. G. Jakeman, W. L. James, C. J. Jewell, L. M. Jockel, H. H. Johnson, J. H. Johnson, Christopher Jones, W. E. Jones, W. P. Jones, J. Joseph, W. Judd, A. E. Keating, A. C. Kelly, Sir A. B. W. Kennedy, F.R.S., W. T. Kerr, J. B. Kilshaw, H. Kingsbury, J. R. Kingston, G. W. Lambert, G. Langdon, W. H. Lea, A. H. Leeves, Major H. P. T. Lefroy, D.S.O., M.C., R.E., A. E. Levin, E. W. Lewis, J. Lingard, G. S. Lisle, W. T. Maccall, C. N. McDermott, W. Macdonald, J. W. McEwan, T. McGrath, Prof. J. T. MacGregor-Morris, Dr. N. W. McLachlan, D. McLennan, H. McNaul, A. J. Makower, M.A., F. J. Mann, Messrs. Marconi's Wireless Telegraph Co., J. W. Meares, C.I.E., S. W. Melsom, Colonel T. H. Minshall, D.S.O., B. E. G. Mittell, W. M. Mordey, B. H. Morphy, C. F. Mounsdon, K. A. Mountain, W. C. Mountain, Captain S. R. Mullard, M.B.E., J. M. M. Munro, E. W. Newman, C. H. Nicholson, J. F. Nielson, C. G. Nobbs, P. W. Northey, W. H. Nottage, Sir A. M. J. Ogilvie, K.B.E., C.B., C. Oliver, V. F. M. Oliver, J. Orringe, F. L. Otter, The Hon. Sir C. A. Parsons, K.C.B., F.R.S., G. W. Partridge, W. H. Patchell, B. Paul, F. G. Payne, W. Pennington, W. E. Poole, W. G. T. Pope, A. H. Preece, N. Prentice, J. E. Price, A. P. Pyne, E. H. Rayner, D.Sc., T. B. Reader, T. Rich, H. W. Richardson, W. O. Ridley, H. R. Rivers-Moore, A. Roberts, R. Robertson, W. J. Robertson, W. H. Robins, F. W. Robinson, S. R. Roget, P. Rosling, G. L. Rosser, H. J. Round, M.C., S. A. Russell, F. Samuelson, H. R. Sanders, J. Sayers, E. W. Scott, the members of the Scottish Centre (per J. Taylor), E. S. Shoults, J. O. Sibree, A. Siemens, F. A. Simpson, H. A. Skelton, Sir W. Slingo, B. R. Smith, B. Spalding Smith, R. T. Smith, S. B. Smith, W. G. Smith, C. H. Smyth, Sir John Snell, T. H. Solomon, B.Sc., R. J. Sowter, H. C. Sparks, C.M.G., H. J. Stenning, C. Stewart, H. Stokes, Rev. R. H. Streatfeild, A. M. Strickland, Dr. H. Stroud, A. J. Stubbs, H. W. Sullivan, E. E. Tasker, Major A. M. Taylor, T. S. Thomas, C. H. R. Thorn, C. P. Tufnell, J. Turner, L. B. Turner, M.A., Dr. J. H. Vincent, T. Wadsworth, Prof. Miles Walker, Capt. R. J. Wallis-Jones, O.B.E., E. Ward, F. Wardrobe, W. W. Watt, H. E. Webb, the members of the Western Centre (per W. Collins), J. W. Wheeler, R. S. Whipple, A. C. Whish, J. W. Williams, W. R. Williams, H. W. Wilson, T. Wood, L. J. Woodcock, J. H. Woodward, J. H. Woolliscroft, L. E. Wood, R. Wright, H. E. Yerbury, and H. W. Young.

The President announced that arrangements had been made for members to dine together at the Engineers' Club after the Ordinary Meeting to be held on the 27th April, 1922.

The discussion on Mr. R. Borlase Matthews's paper entitled "Electro-Farming, or the Applications of Electricity to Agriculture" (see page 725), was continued, and the meeting terminated at 7.55 p.m.

684TH ORDINARY MEETING, 27 APRIL, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 6th April, 1922, were taken as read and were confirmed and signed.

Messrs. C. H. D. Lang and J. O. Girdlestone were appointed scrutineers of the ballot for the election and transfer of members and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Members.

Inada, Sannosuke.
Kennedy-Purvis, Charles Edward, Captain, R.N.
Scotson, Richard Henry.
Tinsley, William Smith.

Associate Members.

Allen, Edgar Rodda.
Bates, Douglas Oswald.
Beattie, Ronald Burnet.
Brear, Edgar.
Carden, Alan Douglas, Lt.-Col., R.E.
Deane, William.
Ebrey, William Robert.
Elias, John.
Ellis, Herbert Edward O.
Everatt, William Charles.
Fraser, Alexander.
Grant, John Alexander.
Gray, Albert.

Associate Member—continued.

Hamer, Ernest.
Hamilton, Charles.
Harris, Frank.
Herring, Horace Edgar.
Inman, Cecil Turner.
Knill, Edward Philip.
Lewis, William Joseph.
McCord, Arthur.
Marston, Saxon Gordon.
Maxwell, Percy Marsh.
Phillips, Charles Francis.
Schofield, Francis Ernest.
Walker, James Clarence.
Ward, James Rookby.
Warren, Sydney Nicholas.
White, Herbert George.
Wright, Edward B.

Graduates.

Anderson, John.
Betley, John Ernest.
Cockerill, Henry Walter.
Donald, James Alexander.
Griffiths, John Oswald.
Grocott, Albert Edward.
Hamilton, Henry David S.
Harris, George Seymour.
Hayes, Philip.
Law, Francis Henry R.
Llorens, Celestino.
Menon, K.
Munro, Hugh.
Newbery, Arthur Frederick.
Shove, Horace Vivian.
Thomas, David John.
Uplap, Narayan Piraji.
Wade, Douglas Ashton L.
Whittenham, Albert John L.

Students.

Alderton, Percy.
Allison, William Leslie.
Alston, Basil Evelyn.
Barrow, Lucien Leacock.
Barry, Hilary Cope.
Berry, Edward Harrington.
Brenton, Donald John M.
Brockway, Cyril Hotston.
Brown, Samuel.
Burnham, George Stanley.
Choudhury, Shafee Uddin A., B.A.
Cribb, Victor Lorrimer.
Croslegh, Derek Charles.
Crouch, William Henry.
Cullen, Frederick Henry B.
Denny, Ronald Joseph.
Dootson, James.
Downing, Charles Henry H.
Duffield, Edgar.
Fulbrook, Alfred Allen.
Geddes, Colin.
Gemmel, Duncan Ferguson D.
Gerty, Harold George.
Hannan, Cecil William.
Hardaker, Ernest Victor.
Hartley, Frederick Ernest.
Hatch, Thomas Parr.
Hodson, Frederick Stuart.
Holton, George Reginald.
Houston, George Herbert M.
Kidd, Francis Harper.
King, Thomas George.
Knight, Alan Weir.
Limon, Harry.
Lythgoe, William Herbert.
McEwan, John Douglas T.
Marrack, Alexander Organ.
Mensforth, Thomas.
Millar, Raymond I. S.
Moyes, Thomas Frederick.
Munro, James Alexander.
North, Francis Percy.
Norton, William Barlow.
Paine, George Richard.
Parker, John Elliss.
Parker, Ralph Henry.
Pennell, Edward Robertson.
Pettit, Cecil George.
Pilkington, Victor Walter.
Plummer, Horace Archibald D.
Prockter, Colin Edward.
Pyott, James Thompson.
Rapson, Ernest Thomas A.
Raymond, Neville John B.
Read, James Percy H.
Rowland, John Joel.
Shilson, Leslie James.
Simmons, Arthur William.
Skelhorn, John Arthur M.
Smith, Arthur Henderson.
Sowerbutts, Cyril Alfred.
Standring, Ian William, B.A.
Stanger, Geoffrey Edward.
Tattersall, William.

Students—continued.

Taylor, Gerald Ernest.
Thomas, Fred Nicholas.
Thompson, Fred.
Tuson, Kenneth Hadley.
Waddecar, Alfred.
Wallis, William George.
Walsh, Sydney Frederick.
Willis, Arthur.
Wright, Alexander Mackay.
Young, John James.

TRANSFERS.

Associate Member to Member.

Baughan, Alfred Henry V.
Bullock, John Burnard.
Edwards, Frederick Henry.
Fisher, Harry Joseph.
Hansford, Richard Vernon, B.Sc. (Eng.).
Marris, George Christopher.
Neate, Ernest Peters.
Sowter, Robert John, B.Sc.

Associate to Member.

Robertson, Alexander Bruce, Jun., D.S.O.

Graduate to Associate Member.

Mason, Percy Herbert.

Student to Associate Member.

Beak, Allan Llewellin.
Meacock, John Harper.
Norris, Eric Douglas T.

Student to Graduate.

Couzens, Dennis Frederick.
Debley, William John F.
Mills, Arthur A.
Sclar, Isaac.

Messrs. F. B. O. Hawes, W. L. Wreford and H. L. Leach were appointed scrutineers of the ballot for the election of new Members of Council.

A paper by Mr. J. A. Kuyser, Member, entitled "Protective Apparatus for Turbo-Alternators" (see page 761), was read and discussed, and the meeting terminated at 7.40 p.m.

22ND MEETING OF THE WIRELESS SECTION, 3 MAY, 1922.

(Held in the Institution Lecture Theatre.)

Professor G. W. O. Howe, D.Sc., Chairman of the Section, took the chair at 6 p.m.

The minutes of the Meeting of the Wireless Section held on 5th April, 1922, were taken as read and were confirmed and signed.

A paper by Mr. C. S. Franklin, entitled "Short-wave Directional Wireless Telegraphy" (see page 930), was read and discussed, and the meeting terminated at 7.35 p.m.

685TH ORDINARY MEETING, 18 MAY, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 27th April, 1922, were taken as read and were confirmed and signed.

The President announced that the scrutineers (Messrs. F. B. O. Hawes, H. L. Leach and W. L. Wreford), appointed at the Ordinary Meeting of the 27th April, had reported to him that they had examined the ballot papers for the election of new Members of Council and that the following persons had been duly elected:

President: Mr. F. Gill

Vice-Presidents: Dr. W. H. Eccles, F.R.S., and Mr. A. A. Campbell Swinton, F.R.S.

Hon. Treasurer : Sir James Devonshire, K.B.E.

Ordinary Members of Council : (Members) Messrs. J. W. Beauchamp, R. A. Chattock, and Major Kenelm Edgcumbe ; (Associate Members) Messrs. F. W. Crawter, A. F. Harmer and W. R. Rawlings ; (Associate) Mr. D. N. Dunlop.

On the motion of the President a vote of thanks was passed to the scrutineers of the ballot.

The President announced that the Council had decided to establish a Faraday Medal of the Institution for notable scientific or industrial achievement in electrical engineering, or for conspicuous service rendered to the advancement of electrical science, without restriction as regards nationality, country of residence, or membership of the Institution, and that the first award of the medal had been made to Mr. Oliver Heaviside, F.R.S., Honorary Member (see page 499).

Sir Oliver Lodge gave a short address (see page 500) on Mr. Heaviside's work.

Sir Ernest Rutherford, K.B.E., F.R.S., then delivered the Thirteenth Kelvin Lecture entitled "Electricity and Matter" (see page 613).

A vote of thanks to the lecturer, proposed by Prof. E. W. Marchant, D.Sc., and seconded by Mr. S. Evershed, was carried with acclamation and the meeting terminated at 7.45 p.m.

50TH ANNUAL GENERAL MEETING, 25 MAY, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 6 p.m.

The Notice convening the meeting was taken as read.

The minutes of the Ordinary Meeting of the 18th May, 1922, were taken as read and were confirmed and signed.

A list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

Messrs. A. H. Allen and A. R. Everest were appointed scrutineers of the ballot for the election and transfer of members and, at the close of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

Members.

Buxton, Ernest Albert.
Lakey, Thomas.
Palairet, Charles Rowland.

Associate Members.

Allwood, Harold.
Blacklock, Charles Wedderburn.
Bose, Surendra Nath.
Brewer, Thomas Henry.
Brown, George.
Brown, Robert Carruthers.
Callanan, Daniel.
Clyne, Joseph Oliver.
Eden-Green, Samuel.
Fanghanel, Walter Paul F., B.Sc.
Farrow, Ernest John.
Fisher, Alexander Wilmot.
Francis, Ernest Sydney.
Franks, Robert Ferguson.
Gardiner, John Richard.
Geddie, Alexander Burgess.
Goodwin, Frederick William.
Green, John Douglas.
Grime, Edward.
King, Sydney.
Macdonald, James.
Mullin, John.
Nearn, Horace Bradshaw.
Polydoroff, Wladimir.
Reed, Frederick William.
Reindorp, Edmund John.
Romain, William Aaron B.
Simpson, Stanlie Summerside.
Storry, Albert.
Tattam, Charles Richard.
Tegetmeier, Norman.
Waddell, Archibald John S.
Wilson, Robert Gardner.

Graduates.

Baines, John Stanhope. Capt., R.E.
Brown, George Victor.
Chinnery, Arthur William.
Cluett, Wallace Edwin.
Cross, Arthur Firman.
Fagge, Arthur Kenelm, B.Sc. (Eng.).
Fyfe, Alexander James.
Habgood, Edwin Valentine C.
Horner, John Wood.
Mackinnon, Alexander.
Roberts, Sidney Douglas.
Rodgers, James Neil.
Ross, Eric Graham.
Swarsbrick, Joseph James.
Targett, Ernest Howard.
Taylor, Edward Hardy.
Watkins, Herbert William.
Webb, Roland, B.A.

Students.

Baldwin, Norman Victor.
Barry, Raymund James.
Blanshard, Herbert William.
Booth, Charles Harry.
Booth, Clifford.
Brocklesby, Charles Willie.
Brown, Arthur.
Brownlie, William.
Buckingham, Robert George S.
Bull, Reginald Alfred.
Burton, Donald Graham.
Chamberlain, Ronald Henry.
Claudius, Cecil Dinger.
Cooper, Edward Cecil.
Cox, William Leonard.
Crymble, Clarence Frederick.
Dashwood, Edmund Kerrison.
Dibben, Ernest.
Dumbrell, George William.
Glendinning, William.
Hall, James Stewart.
Hart, Daniel.
Hooper, Ewart Henry.
Horton, Albert Edward E.
Hunt, Herbert Cunningham.
Joseph, John Reynolds.
Lamond, James, B.Sc. (Eng.).
Lavender, Leslie Charles G.
Lindsay, Andrew Wentworth.
Lochner, Robert Arthur.
Loureiro, Thomaz Edson.
McDonald, John Alexander.
Mactaggart, Hugh.
Mangnall, Wilfrid Earlam.
Mayes, Edric Arthur.
Mitchell, William Robert.
Moriarty, James Edward.
Murrell, Henry John A.
Pilgrim, George Jack.
Rainford, Herbert.
Rose, Leslie Raymond C.
Seccombe, Raleigh Frederick M.
Smith, John Dudley.
Thornton, David Martin.
Whitfield, Eric Gardner.
Whyman, Frank.
Williams-King, Evan Baker.
Youdan, Denis.

Associates.

Burbury, Henry Herbert T.
Ferguson, Harry Edmund.
Green, Arthur Leonard.
Scott, William Albert, J.P.

TRANSFERS.

Associate Member to Member.

Angwin, Arthur Stanley, B.Sc.(Eng.), D.S.O., M.C.
Billington, John Dutton.
Blake, George Gascoigne.
Breach, Leonard.
Burchell, John George.
Burrowes, Richard Beresford.
David, Major Edward I.
Fowler, Cecil Charles.
Higham, Ralph Gilson.
O'Neill, James Wooldridge.
Sills, George Francis.
Smith, John Robert.
Waite, James Nixon.
Warren, John William F.
Wilson, John, O.B.E.
Wilson, William Smith.
Wright, Frank Thomas, Major, M.B.E.

Graduate to Associate Member.

Atkinson, Colin Eric.
Chester, Clifford Ernest, B.Eng.
Fox, Herbert Christopher.
Gordon-Campbell, William Francis.
Hall, Denis Kingston.
Hilton, Christopher Frederick, Capt., R.E. (T.).
Hopkin, David William.
Park, Harold Edward.
Shepherd, James Ernest.
Travers, Archibald.

Student to Associate Member.

Balbi, Charles Mackenzie R.
Emanuel, Charles William.
Gomersall, William Charles.
Parker, Vincent Henry G.
Rosen, Abel.
Snell, John Basil, Lieut., R.E.

Student to Graduate.

Duff, W. V. Hobart.
Glew, Ernest Lownds.
Munday, Sydney George.
Pennington, John Hawley.
Pointon, Herbert Vincent.
Read, Robert Charles.
Swift, Bernard.
Taylor, Herbert Willott.
Whitfield, Charles Millard.

The following lists of donations were taken as read and the thanks of the meeting were accorded to the donors :—

Benevolent Fund : R. Ainsworth, Major E. O. Alabaster, R.E., G. Allom, K. N. Arnold, H. J. Aylott, C. J. Baker, S. Baldwin, E. Barlow, A. G. Barnard, A. S. Barnard, H. Bastable, E. H. Baxter, R. B. Beattie, A. L. Bedford, S. Beeton, E. G. Bell, W. Bird, C. A. Boraston, G. W. Bousfield, F. G. Briant, E. E. Briggs, J. C. Briggs, C. H. Brockway, J. S. Brown, Walter Brown, J. Burns, G. B. Burrows, W. Burton, Lt.-Col. A. D. Carden, R.E., J. L. Carr, J. H. Carrick, C. B. Chartres, R. A. Chattock, G. A. Cheetham, B. C. Clayton, W. A. Coates, A. D. Constable, G. W. Cooper, J. F. Dale, A. J. Dalton, J. C. J. Dalton, I. Davies, A. E. Dawson, R. J. Denny, E. Dixon, H. M. Douglas, H. M. Dowsett, J. P. A. Drewry, P. C. Ebner, The Electrical Engineers' Ball Committee (per A. M. Sillar), W. Fennell, L. G. Fenner, Messrs. Ferguson, Pailin, Ltd., Prof. C. L. Fortescue, A. E. Frankling, F. H. Francis, A. A. Fulbrook, E. Garcke, A. W. Gardner, E. A. Gatehouse, F. W. Geoghegan, C. G. Glass, P. Good, J. Hunter Gray, K.C., Horace Green, L. Griffiths, J. Gurney, H. S. Hamilton, N. E. P. Harris, J. E. Hartley, T. H. Martin Harvey, F. N. Haward, J. C. Hawkhead, W. C. C. Hawtayne, V. J. Hegney, H. J. Henwood, W. E. Highfield, W. Higson, F. S. G. Hinings, L. B. Hobgen, J. P. Hodges, W. Hodson, W. A. Hole, W. F. M. Horne, P. S. Hudswell, L. J. Hunt, G. Hunter, R. J. Huntley, F. W. Hutton, E. S. Jacob, E. W. James, L. B. Jeffery, V. N. Jolliffe, H. H. Jowers, Dr. G. Kapp, J. T. Keay, C. E. Kennedy-Purvis, A. J. N. Kennett, J. E. Kingsbury, H. C. Lamb, A. Latham, J. H. Leigh, L. J. Lepine, the Liverpool Sub-Centre (per W. Lang), E. P. Lovell, A. McCord, J. C. Macfarlane, H. T. McKinnon, C. W. Mallins, R. W. Manifold, E. Manville, A. O. Marrack, J. Martin, W. J. Minton, C. W. G. Nelson, R. Nelson, G. O. Nevile, C. G. M. New, A. S. Newman, the North Midland Centre (per J. D. Bailie), C. Oliver, W. G. Palmer, H. Parker, W. Pate, A. S. Peek, J. W. Piggott, C. W. Pike, F. E. Price, E. E. Putland, I. Rigby, R. Robertson, B. A. Robinson, T. Roles, P. Rosling, D. Ross, G. Ross, A. H. Rowles, S. A. Russell, W. V. Ryder, H. Saunders, J. Sayers, W. H. Scott, F. Shakeshaft, G. M. Sichel, M. G. Simpson, H. A. Skelton, J. A. Slee, Dr. S. P. Smith, C. H. Smyth, J. H. Southern, A. C. Stewart, C. Stewart, H. S. Stride, Major-Gen. Sir A. M. Stuart, K.C.M.G., C.B., H. S. Styan, W. E. Swale, W. H. T. Swire, W. C. P. Tapper, J. H. Targett, N. S. Tennant, N. A. Thompson, W. S. Tinsley, T. D. Trees, E. J. Turnbull, J. W. Turner, C. J. Vaughan, O. V. Waddington, H. Waizborn, J. C. Walker, T. Walmsley, E. C. Watson, P. D. Webb, W. S. Weir, A. J. L. Whittenham, A. G. Whyte, F. H. Williams, W. Wilson, K. L. Wood, W. B. Woodhouse, C. E. Woodward, H. G. Wright, H. E. Yerbury, H. W. Young, and J. J. Young.

Building Fund : W. M. Mordey.

Library : The Air Ministry (Director of Research, Meteorological Office, and Technical Committee on Radio Communication), W. Aitken, Messrs. Attwater & Sons, Prof. F. Bacon, A. Blondel, C. Alfred Baker, Messrs. Benn Brothers, Ltd., Messrs. Ed. Bennis & Co., Ltd., L. Birks, The Board of Trade, The British Electrical and Allied Industries Research Association, The British Engineering Standards Association, The Department of the Interior (Canada), The Dominion Bureau of Statistics (Canada), The Chief Inspector of Factories (Home Office), Messrs. Chapman & Hall, The Chartered Institute of Patent Agents, The Comitato Nazionale Scientifico-Technico (Italy), The Comptroller-General of the Department of Overseas Trade, The Director General of Posts and Telegraphs (India), H. M. Dowsett, The Edison Pioneers, The Electricity Commissioners, E. Garcke, Messrs. The General Electrical Co., Ltd., Sir Robert Hadfield, Bart., F.R.S., Harvard University, C. C. Hawkins, The Hydro-Electric Survey of India, The Imperial Mineral Resources Bureau, The Incorporated Municipal Electrical Association, The Institution of Engineers (India), The Institute of Chemistry of Great Britain and Ireland, The Institution of Heating and Ventilating Engineers, The Institution of Petroleum Technologists, Dr. A. E. Kennelly, G. C. Lamb, Messrs. A. P. Lundberg & Sons, A. E. McDonell, Messrs. Marconi's Wireless Telegraph Co., Ltd., B. E. G. Mittel, R. L. Morrison, S. Narayan, A. McL. Nicholson, Sir Andrew Ogilvie, G. D. A. Parr, W. H. Patchell, H. E. Poole, H. W. Price, The Public Works, Roads and Transport Congress and Exhibition, 1921, Messrs. S. Rentell & Co., Ltd., S. R. Roget, Messrs. Smith, Kempe and Smith,

F. J. M. Stratton, Messrs. E. & F. N. Spon, Ltd., The Tasmania Hydro-Electric Department, W. T. Taylor, Messrs. The Technical Publishing Co., Ltd., The Uniform Railway Gauge Commission (Australia), S. Utting, Dr. R. M. Walmsley, E. B. Wedmore, and C. H. Yeaman.

The President, after summarizing the Annual Report of the Council for the year 1920–21 (see page 526), moved "That the Annual Report of the Council for the year 1920–21 as presented be received and adopted."

The Resolution was seconded by **Captain R. J. Wallis-Jones** and, after being put to the meeting, was unanimously adopted.

Sir James Devonshire, K.B.E. (Honorary Treasurer), moved the following Resolution: "That the Statement of Accounts and the Balance Sheet for the year ended 31st December, 1921,* as presented be received and adopted." In doing so, Sir James Devonshire said:—

It is now my duty to submit the Statement of Accounts for the past year. Taking first the income and expenditure, as will be seen by the printed Report which has been issued to members, there is a surplus on the Revenue Account for 1921 of £639 2s. 10d. after making the provision of £4 000 for the Reserve Fund. This amount, which had been carried to the General Fund, compares with £673 7s. 1d. in 1920, and shows a decrease of £34 4s. 3d., but it should be pointed out that last year only £3 000 was put to Reserve, as against £4 000 for the year 1921. The total expenditure for 1921 is £29 921 14s. 9d. That figure does not, however, appear in the Accounts, for the following reason. It includes the amount of rent from tenants, which has hitherto been shown on the Revenue side, but on this occasion has been subtracted from the Expenditure side of the Accounts. This figure of £29 921 14s. 9d. compares with £28 010 8s. 10d. in 1920, and shows an increase of £1 911 5s. 11d. The principal items of this increase occur under the heads of "Management," which is up by £912; "Institution Building and Temporary Offices," which are £1 519 more; "Science Abstracts," which increases by £717; and the expenditure in connection with the Royal Charter, namely, £309. On the other hand, there are savings under special heads, notably "Journal," £1 803; "Legal Expenses," £197; "Stationery," £153; and "Mortgage Interest," £97. The last reduction is mainly due to the voluntary repayment of £4 000 to the Economic Life Assurance Society in 1921. On the credit side of the Account the Income shows an improvement of £4 374 (after making the adjustment in regard to the rents from tenants), mainly due to the increased subscriptions, which brought in an extra £6 041, and this in turn is offset by a decrease in the rents from tenants. Entrance Fees increased by £155 during the year. On the other hand, no amounts were received for Life Compositions, as compared with £315 in 1920. The decrease in the rents from tenants amounts to £1 749, viz. £4 866 as against £6 615, due to the termination of the occupation of the Institution building by H.M. Office of Works in June 1921. These rents will be further reduced in 1922, when the Institution will have occupied its own premises for the whole year. In addition, the London County Council will be giving up their tenancy of the second and third floors at the end of the June quarter, but this will be partly made up by the lettings which have been effected of some of the vacant rooms on the first floor. The rents from the Tothill-street property show an increase of £233, but owing to special expenditure on repairs, increased rates, auction fees, etc., the net profit is reduced by £47, from £557 to £510. The benefit of the increased rentals will, however, show in future years.

Turning now to the Balance Sheet, the first item is "Economic Life Assurance Society," which last year stood at £29 284 15s. and was reduced in 1921 to £24 331 19s. 11d. by £4 952 15s. 1d. made up of two items, viz. the amount of the obligatory repayment to the Society, and the voluntary repayment, to which I have previously referred, of £4 000 from the Reserve Fund. As a consequence of this substantial reduction of the mortgage, the interest payable is now materially reduced. Under the heading "H.M. Office of Works (Suspense Account)" appear two items for amounts claimed by the Department and the Institution respectively, arising out of the occupation of the building by the Government. These two items are at present the subject of negotiation with the Department, and therefore I prefer to say nothing more about them. The Reserve Fund (Contingencies and Mortgage Redemption) was increased by a transfer of £4 000 from the Income and Expenditure Account, and reduced by the amount of the voluntary repayment of £4 000, the total being £14 000 as in 1920. The General Fund now stands at £88 700 4s. 11d., as compared with £82 370 16s. 10d. on 31st December, 1920. Turning now to the Assets side, the value of the Institution Building and Lease is shown as £69 371 14s. 2d., as against £69 727 5s. 5d. in 1920, a difference of £355 11s. 3d. This is accounted for by the fact that the Surrender Values of the Sinking Fund policies increase each year by a larger amount than the annual premium of £277 12s. 2d. paid in respect of the policies. As members are aware, these policies have been taken out in order to secure the principal sum of £75 000 at the termination of the lease of the Institution building in 1984. During the year a sum of £86 1s. was released from the Life Compositions Fund in respect of deceased members, and has been added to the General Fund. In order to make the Life Compositions investments less than the Fund, a small transfer of stock of the nominal value of £100 has been made from the Life Compositions investments to the General Fund investments, the total of the two investments remaining the same. The statement in the Council's Report (see page 535) relating to the surplus of Assets over Liabilities is shown in the amended form adopted for the first time in the 1920 Accounts, in which the values of the actual properties shown on the Assets side, less the Liabilities, are given in full. These figures reveal that this surplus is now £108 939 7s. 11d., that is, an improvement over 1920 of £6 243 7s. 1d. There is one last matter to which I should like to refer. The Trust Funds Capital Accounts of £8 913 18s. 5d. were shown in the Balance Sheet in in the year 1920, but it will be observed that they do not appear in this year's Balance Sheet; they are given on the next two pages (pages 542 and 543). The amount,

* See page 538.

however, has not changed. Of course the balances of income from these Trust Funds are brought into the Balance Sheet, but the Capital Accounts are kept distinct and shown separately. In conclusion, I think the Institution has every reason to be gratified with its financial position as disclosed by the Accounts, which I now submit for adoption, and I formally move "That the Statement of Accounts and the Balance Sheet for the year ended 31st December, 1921, as presented, be received and adopted."

The Resolution was seconded by **Mr. F. W. Crawter** and, after the Honorary Treasurer had replied to a few comments by **Mr. F. W. Purse,** was unanimously adopted.

The following Resolution moved by **Mr. Ll. B. Atkinson,** seconded by **Mr. F. W. Purse** and supported by the **President,** was carried with acclamation: "That the best thanks of the Institution be accorded to the following officers for their valuable services during the past year: (*a*) The Honorary Secretaries of the Local Centres and the Local Honorary Secretaries and Treasurers abroad; (*b*) the Honorary Treasurer (Sir James Devonshire); (*c*) the Honorary Solicitors (Messrs. Bristows, Cooke and Carpmael)."

Mr. P. Rosling then moved "That Messrs. Allen, Attfield and Co. be appointed auditors for the year 1922–23." The Resolution was seconded by **Mr. A. F. Harmer** and carried unanimously.

The meeting terminated at 6.50 p.m.

23RD MEETING OF THE WIRELESS SECTION, 7 JUNE, 1922.

(Held in the Institution Lecture Theatre.)

Professor G. W. O. Howe, D.Sc., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting of the Wireless Section held on the 3rd May, 1922, were taken as read and were confirmed and signed.

The Chairman reported that no nominations having been received from members of the Section for the Wireless Section Committee, the Committee's nominees (see *Institution Notes*, No. 33, page 21, May 1922) had been duly elected.

The Chairman also announced the premiums awarded by the Council for papers read before the Wireless Section during the Session 1921–22 (*see* Report of the Council, page 528).

A paper by Mr. Norman Lea, D.Sc., Associate Member, entitled "The Performance of a Radio-Telegraphic Transmitter, with Special Reference to the New Installation at North Foreland" (see page 942), and a paper by Professor C. F. Jenkin, C.B.E., M.A., Member, entitled "A Dynamic Model of Tuned Electrical Circuits" (see page 939), were read and discussed.

The meeting terminated at 7.50 p.m.

BENEVOLENT FUND.

24TH ANNUAL GENERAL MEETING, 25 MAY, 1922.

(Held in the Institution Lecture Theatre.)

Mr. J. S. Highfield, President, took the chair at 5.45 p.m.

The Notice convening the meeting was taken as read.

The minutes of the 23rd Annual General Meeting held on the 26th May, 1921, were taken as read and were confirmed and signed.

The Report of the Committee of Management (see page 920) and the Statement of Accounts for the year 1921 (see page 544) were presented and, on the motion of the Chairman, seconded by Captain R. J. Wallis-Jones, were unanimously adopted.

The Institution of Electrical Engineers was appointed a trustee of the Fund in place of the late Mr. W. Duddell, F.R.S.

On the motion of the Chairman it was unanimously resolved that Mr. J. Attfield, F.C.A., be elected Honorary Auditor for the year 1922–23.

The Chairman reported that under Rule 10 the Council had appointed the following Committee of Management for the year 1922–23:—

The President (*ex-officio*).

Mr. H. J. Cash
Mr. S. Evershed
Mr. J. R. Cowie
Sir A. M. Ogilvie, K.B.E., C.B.
Dr. A. Russell
Mr. A. A. Campbell Swinton, F.R.S.
} Representing the Council;

Mr. W. B. Esson
Mr. J. E. Kingsbury
Colonel H. C. Sparks, C.M.G., D.S.O., M.C.
} Representing the Contributors;

and the Chairman of each Local Centre in the United Kingdom.

The meeting then terminated.

REPORT OF THE COMMITTEE OF MANAGEMENT FOR THE YEAR 1921.

Capital.

The Capital Account has been increased during the year by a transfer of £2 149 17s. 9d. from the accumulated Income Account, and now stands at £7 859 7s. 3d., all of which is invested.

Receipts.

The Income for 1921 from dividends, interest and annual subscriptions was as follows :—

	£	s.	d.
Dividends on investments	311	12	8
Interest	34	7	3
255 annual subscriptions	201	6	0
	£547	5	11

In addition to the foregoing, the Fund benefited during the year by the following, many of which are non-recurring donations :—

Ordinary Donations :

	£	s.	d.
Electrical Engineers' Ball Committee ..	63	0	0
W. T. Henley's Telegraph Works Co. Ltd.	25	0	0
"Twenty-five" Club	15	15	0
Incorporated Municipal Electrical Association	10	10	0
F. R. Marsh	10	0	0
J. D. Dallas	5	0	0
Col. H. C. Sparks	5	0	0
and 761 non-recurring donations of under £5	280	14	9
	£414	19	9

Special Donations :

(Mr. Hughman's appeal)	£808	11	6

The balance of the Income and Expenditure Account amounted on 31st December, 1921, to £1 583 16s. 9d., of which £1 375 was on deposit with the Institution bankers. Since that date an amount of £2 113 4s. 3d. has been invested in 5 per cent National War Bonds, and £499 8s. 6d. in 5 per cent War Stock (1929–47). With these two investments the Capital Account now stands at over £10 000.

Donors and Subscribers.

Lists of the names of donors and subscribers during 1921 have been published in the *Journal*.

The Committee of Management desire to acknowledge their indebtedness to the donors and subscribers, and they venture to urge upon members the pressing need for a generous support of the Fund. Apart from donations, the Committee will be grateful for annual subscriptions even of small amounts.

Offer from Mr. E. M. Hughman.

Reference was made in the last Annual Report to the generous offer of Mr. E. M. Hughman (late of Bombay) to present £250 to the Fund, provided 19 other donations of a similar amount were received by the 30th June, 1921. Subsequently, Mr. Hughman was good enough to extend the date to the 31st December, 1921, and entirely to waive his conditions both as to the number and the amount of the other donations. An appeal based on the offer was widely circulated and the result has been that the Fund has already (3rd April, 1922) benefited to the extent of £2 306 6s. 5d. as follows :—

	£	s.	d.
Individual contributions	1 120	10	0
Collected by Local Centres and Sub-Centres	508	11	5
Collected from members of Wireless Section by Dr. W. H. Eccles	409	18	0
Collected from Post Office Engineers by Sir William Noble	267	7	0
	£2 306	6	5

The Committee of Management was deeply grateful to Mr. Hughman, the other donors, and those who made "group collections," for the valuable assistance rendered by them to the Fund.

Grants.

Applications for assistance were made by or on behalf of 14 persons during 1921, and the Committee, after due consideration, made grants in all the cases. One grant was made of £100, one of £80, four of £50, three of £25, two of £22, one of £20, one of £4 5s. and one of £2, a total of £525 5s.

Appointment of Local Honorary Treasurers.

The Council of the Institution have approved the suggestion of the Committee of Management that a Local Honorary Treasurer to the Benevolent Fund be appointed in each of the Local Centres to be responsible each year for a collection from the Centre for the Fund.

Several of the Local Centres have already appointed Local Treasurers for this purpose.

Wilde Fund.

The Capital Account stood on the 31st December, 1921, at £2 586 19s. 2d., the whole of which is invested and brings in an annual income of £89 12s. 5d.

The balance standing to the credit of the Income Account, from which, under the Trust Deed, full Members only can benefit, on the same date was £194 14s. 5d. This amount has, since that date, been invested in 5 per cent National War Bonds.

No grant from this Fund was made during the year.

AN OSCILLOGRAPH INVESTIGATION OF THE GULSTAD RELAY.

By S. S. Richardson, D.Sc.

(*Paper read before the* Liverpool Sub-Centre, 20*th February*, 1922, *and received in final form*, 31*st July*, 1922.)

Summary.

The paper deals with an examination, by means of the oscillograph, of the details of the current-changes in the auxiliary and line circuits of the Gulstad high-speed vibrating relay. The results include :—

(1) Variation of the current in the two branches of the auxiliary circuit.
(2) Resultant of the auxiliary currents determining the magnetization of the relay cores.
(3) Influence of leak circuits.
(4) Effect of a closed line circuit and operation of the line currents.

The circuit connections used in the tests are given and a new type of frequency meter devised by the author is described.

Introduction.

In view of the increasing application of the vibrating relay to telegraph lines subject to considerable attenuation and distortion, a knowledge of the precise nature of the variations in the currents which operate the relay becomes a matter of some importance to the telegraph engineer. Although the action of this particular relay is of course understood so far as general principles are concerned, it occurred to the author that more exact information as to the nature of the current-changes involved would be both of interest and utility. The present paper is the outcome of a number of experiments made with the aid of the oscillograph with this particular object in view.

It may be well to state first the general principle underlying the action of a vibrating relay, which is briefly as follows. When Morse is being worked through a long overhead line or a cable, a rapid succession of positive and negative currents at the sending end becomes so smoothed out or attenuated through the capacity of the line that the currents for a succession of dots may not be of sufficient strength to operate the receiver, and high-speed working without some special device becomes impracticable. Owing to their longer duration the currents forming the dashes and the negative currents forming letter or word spaces are better received. In the Gulstad relay the device is adopted of keeping the tongue of the relay in regular vibration, isochronous with the transmitter, by means of a special local circuit, and if there is no current in the line a succession of dots will be automatically recorded. If, therefore, during actual transmission the dashes and long spaces come through with sufficient intensity momentarily to stop the vibration the signals will be correctly recorded. Thus in Fig. 1 by preventing the formation of spaces at B and D, and preventing the formation of marks at A, C and E, the succession of dots becomes converted into the signals L, T. It will be noticed further that the temporary suspensions of the regular vibration occur only in the middle of the received dashes and letter (or word) spaces, i.e. only in the middle of the longer positive and negative current pulses. Hence, provided

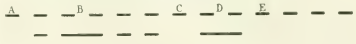

Fig. 1.

these longer pulses only are received with sufficient intensity, the signals will still be correctly recorded.

In his original account of the development of the vibrating relay, K. Gulstad * describes circuit arrangements which provide satisfactory contacts both with and without special windings on the electromagnet. In a later paper † the latter method is more fully considered and is shown to be more satisfactory. The relay used for the tests described below is of this type and was kindly lent to the author by the Automatic Telephone Manufacturing Company for the purpose.

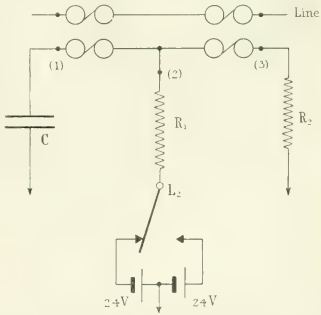

Fig. 2.

The instrument shown in Fig. 2 resembles the P.O. standard B relay in general design but, in addition to the (100 + 100)-ohm differentially wound line coils, is provided with two windings on the same cores each of 100 ohms but of smaller inductance than the line coils, and connected between the terminals marked

* *Electrical Review*, 1898, vol. 42, p. 751.
† *Ibid.*, 1902, vol. 51, p. 294.

(1)–(2) and (2)–(3), respectively. A current from terminals (2) to (1) or (3) to (2) moves the tongue towards the marking stop. The terminal L_2 of the tongue is connected through a resistance R_1 to the terminal (2), while the spacing and marking contacts are joined respectively to the negative and positive poles of a (24 + 24)-volt split battery. The terminal (1) is joined through the condenser C to earth, and terminal (3) through a non-inductive resistance R_2 to earth. It will be convenient to refer to the former as the "condenser branch," and the latter containing inductance and resistance only the "inductive branch." The local circuit containing a Wheatstone receiver or an undulator is joined in leak to the tongue L_2.

The steady vibration is maintained by electrical action only. When the tongue strikes the positive stop, a current flows through R_1 and divides between the condenser and inductive branches. At first the current charging the condenser is much the stronger of the two parts, but rapidly dies away as the condenser charge approaches its full value. The current in the other branch, however, steadily grows to a maximum and a point is reached where it overbalances the condenser current and the tongue is pulled over to the opposite stop, on striking which the tongue is joined to the battery of opposite polarity and similar changes take place with reversed currents. It should be noted that on *either* side the condenser current produces a "holding-on" effect and the other current a "pulling-off" effect.

The frequency of the regular vibrations so produced depends on the inductance and resistance of the auxiliary windings and also on R_1, R_2 and C. The frequency is adjusted to the value appropriate to the speed of transmission by adjusting the values of the last three quantities. The following table gives some typical values.

C	R_1	R_2	Frequency
μF	ohms	ohms	~ per sec.
29	1 480	3 000	3
9	1 480	3 000	8
5	1 480	3 000	11·6
29	1 480	200	18
5	100	3 000	20
4	100	1 500	46
4	100	700	89

The frequency is given in the last column in periods per second, a period being equivalent to a dot plus a space of equal length. The number of words per minute may be found from the relation

$$\text{words per minute} = 2{\cdot}5 \times \text{periods per second.}$$

In the Gulstad relay made by the Automatic Telephone Manufacturing Comapny the poles of the electromagnet, by means of a suitable screw movement, can be made to approach the armatures or recede from them, an adjustment which allows a variation to be made in the sensitiveness, degree of bias, and frequency, within certain limits.

The play of the tongue in the following tests was varied between 1 and 2 mils. The play was measured at the striking end of the tongue with the aid of a micrometer microscope reading to 0·005 mm (or $\frac{1}{5}$ mil).

Theoretically the tongue should be set neutral; it is clear, however, that (assuming perfect symmetry of construction) if the tongue has any play at all, then when it rests against either stop the armatures will be nearer to one electromagnet than to the other and will tend to remain there until a certain degree of opposing polarity is established. This unavoidable bias in a relay which is otherwise "neutral" or magnetically symmetrical will be referred to as the *deflectional* bias to distinguish it from the ordinary bias which refers to the effect of unsymmetrical setting of the armatures, or stops.

The oscillograph used was of the permanent magnet (Duddell) type with falling-plate camera. The resistances of the vibrators with fuses were each about 13 ohms. The natural frequency of the vibrators was of the order of 1/3 000 second, and it will therefore be understood that very small irregularities in the current wave-forms are not recorded with quantitative accuracy, but will still fairly represent the nature and direction of such changes. By connecting one vibrator in series with the condenser branch of the auxiliary circuit and the other in series with the inductive branch the simultaneous changes of current in the two branches could be followed. Marking currents are represented by ordinates above the zero line, and spacing currents by those below, and as regards time the curves must be followed from left to right. It is assumed that the changes in magnetization of the cores can be taken as being fairly proportional to the changes of current in the coils.

Operation of the Auxiliary Currents.

Fig. 3 shows a typical oscillogram obtained with the arrangement shown in Fig. 2, without leak or other accessories. At the point M the tongue makes contact with the marking stop. The condenser begins to charge and the charging current rises rapidly to a maximum at the point A. This current is in such a direction that it tends to hold the armature over to the marking side, an effect which is an important function of the condenser and results in firm contacts being made. The opposing current MNC in the inductive branch meanwhile increases more slowly, and at first its effect is overbalanced by the condenser current. The sharp rise in the latter is due to the small inductance (0·05 H) of the auxiliary windings. As the condenser becomes more fully charged the current feeding it diminishes in strength and finally becomes weaker than the steadily increasing current in the inductive branch. When the difference between the currents becomes magnetically equal to the deflectional bias the armature is no longer attracted and immediately afterwards the tongue begins to leave the marking stop. This is shown at B_1C, the ordinate of C being greater than that of B_1. The parts B_1D and CD represent the passage of the spark at break, and during this period the condenser current reverses. At the point D the spark is extinguished and the battery is disconnected from the tongue. The condenser, now discharging, is thus brought into series with the inductive branch and the same current flows

through each, as shown by the fusion of the two curves at D. This current varies very little during the remainder of the transit period DS, owing to the slow discharge of the condenser through the high resistance R_2. At S the tongue comes within the potential spark-range followed by a slightly "chattering" contact, as shown by the indentations at K.

The firmness of contact obtained with the Gulstad relay will be apparent from a comparison of Figs. 4 and 4(*a*). The latter gives the local currents from an

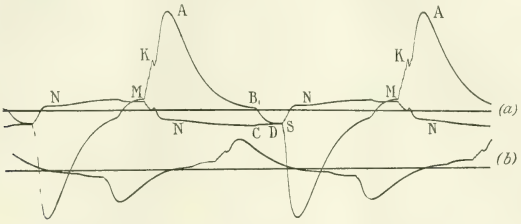

FIG. 3.

(*a*) Auxiliary components. (*b*) Resultant $\times$ 3. $R_1 = 100$; $R_2 = 1\,200$; $C = 10\,\mu F$.

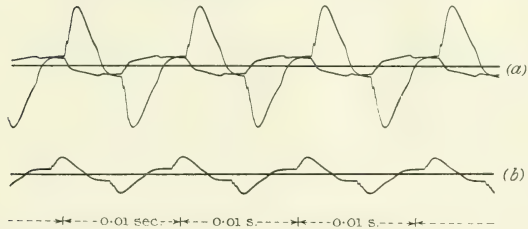

FIG. 4.

(*a*) Auxiliary components. (*b*) Resultant. $R_1 = 150$; $R_2 = 1\,200$; $C = 3{\cdot}5\,\mu F$; $n = 90$.

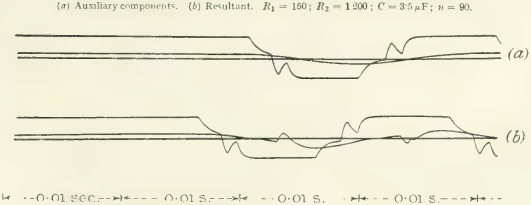

FIG. 4(*a*).—Line voltage (flat-topped) at tongue of sending relay and received line current for dash-dot signal.

(*a*) Auxiliary not working. (*b*) Auxiliary working.

(about 100 volts per mil) of the spacing contact, and the same changes are then repeated with reversed voltage.

Fig. 4 is a similar oscillogram for higher frequency. The condenser discharge is here incomplete when reversal occurs. It will be noticed in Fig. 3 that one transit is followed by a firm "hold on" whereas the other is ordinary B relay, and the large indentations are due to the rebound of the tongue.

Owing to the relatively high value of R_2 the rate of charging the condenser is affected very little by this resistance and depends almost entirely on the values of C and R_1. On the other hand, the rate of growth of

the current in the inductive branch is retarded considerably by the initial heavy condenser current, owing to the fall of potential in R_1 which is occasioned by this current. This is shown on the oscillograms by a distinct depression towards the zero line at the point N opposite the point A of maximum condenser current. This result has suggested a change from the system usually adopted, namely to join R_1 between the condenser and earth or between the condenser and relay, in which position it still acts as a retardation coil for the condenser but not for the inductive branch. This change has resulted in an increase of the frequency of as much as 50 per cent and, therefore, becomes a distinct advantage where high-speed working is required. Owing to the relatively small current in the inductive branch we may calculate approximately the time taken by the condenser current to rise to its maximum, which time determines the "holding-on" effect. An example of this calculation is given in the Appendix. The numerical values thus found agree within reasonable limits with measurements made on the oscillograms.

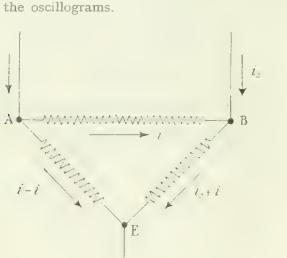

FIG. 5.

A further point which should be noticed is that for the greater part of the transit of the tongue the condenser current is reversed from the "holding-on" direction, and therefore helps to accelerate the movement of the tongue from one contact to the other and thus to give more clearly-cut signals.

RESULTANT OF THE AUXILIARY CURRENTS.

In order to obtain a record of the resultant magnetizing effect of the currents in the two branches of the auxiliary circuit without having recourse to geometrical construction, the device shown in Fig. 5 was used. This the author believes will be of interest in connection with tests on differential relays in general, as it provides a method of obtaining the resultant effect in terms of a single current.

The network ABE consisting of three equal resistances of, say, r ohms each, was connected between the end A of the condenser branch, the end B of the inductive branch, and the earth E. Denoting the currents in the branches by i, and equating the fall of potential along AE to that along AB and BE, we have

$$(i_1 - i)r = ir + (i + i_2)r, \text{ or } i = \tfrac{1}{3}(i_1 - i_2) \quad . \quad . \quad (1)$$

The current i is therefore proportional to the resultant of the opposing currents i_1 and i_2. This applies during the period of contact with the battery terminals. During the period of disconnected transit (DS in Fig. 3) no current flows to earth at E, but the current, say i', common now to the two branches divides at A, two-thirds of it flowing along AB and one-third along AEB. Bearing in mind that i' flows through the two magnet coils in series, its effect is equivalent to $2i'$ in one coil only. Hence during the transit period the current in AB is

$$\tfrac{2}{3}i' = \tfrac{1}{3}(2i') \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Thus, comparing equations (1) and (2) we see that one-third of the resultant magnetizing current flows through AB not only during the period of contact, but also during the transit period, and if one of the vibrators (or other measuring instrument) forms AB the resultant will be indicated. In the tests the resistance of the vibrator section AB was 13 ohms, and AE, BE were two non-inductive resistances of 13 ohms each. The presence of a low-resistance mesh connected in this way has no appreciable effect on the general distribution of current in the remainder of the auxiliary circuit. The lower curves in Figs. 3 and 4 show the resultant of the current indicated by the upper curves, of course with ordinates reduced in the ratio 3 : 1, though the resultant and components do not correspond in their positions with regard to the time axes.

INFLUENCE OF LEAK CIRCUITS.

In place of an actual receiver in the experiments a frequency meter (which will be described separately) of inductance 2·5 H was used, in series with a non-inductive resistance of 2 000 ohms.

During the transit of the tongue the leak circuit is supplied with current from the condenser, and the receiver current is thus maintained at practically its full value until contact is made with the other stop. It will also be noticed that, as the condenser is now feeding both the inductive auxiliary and the leak, the reversal of the condenser current is accelerated and the frequency is increased. The "fusion" of the auxiliary currents already noted of course no longer occurs, and there is a distinct drop in the inductive branch current at the moment of break (see Figs. 7 and 8).

Effects similar but less marked are produced by the anti-spark condenser leak, the presence of this circuit also increasing the frequency.

THE EFFECT OF A CLOSED LINE CIRCUIT.

In the experiments with the line circuit the apparatus was arranged as indicated in Fig. 6. A phonic wheel interrupter driven by direct current and controlled by an electrically maintained tuning-fork was used as transmitter. The phonic wheel and interrupter are shown separately in the figure, but are rigidly connected to the same shaft in the actual apparatus. The speed could be controlled by the tuning-fork, which was adjustable as regards frequency. The interrupter has two series of contacts and is so arranged that by means of a two-way switch (not shown in the figure) the signals can be changed from a succession of dots to alternate dots and dashes. The contacts for dots only

are shown in the diagram. By means of a network W arranged as an unbalanced Wheatstone bridge, the simple make and break of the phonic wheel contacts was caused to generate reversals of current in the coils of the sending relay, the make short-circuiting one arm of the bridge and the break disconnecting it. The contacts of the relay were joined to the (24 + 24)-volt battery, and the tongue to line, also to an anti-spark condenser leak. The artificial line was adjustable in respect of capacity, resistance and leakance, the last being continuously variable by means of a sliding contact. The remainder of the connections were the noticed that the latter is very marked and the break is now delayed until the auxiliary resultant has reversed sufficiently to overcome the deflectional bias and the current induced in the line. The closing of the line circuit, therefore, reduces the frequency from this cause, but, owing to the fact that the inductance of the auxiliary winding is at the same time slightly reduced, and its effective resistance increased, there is an opposing tendency to increase the frequency. The line in this case had a resistance of 2 640 ohms with a 2 000-ohm leak and 4 μF capacity. With larger line capacities met with in practice the effect will be much greater.

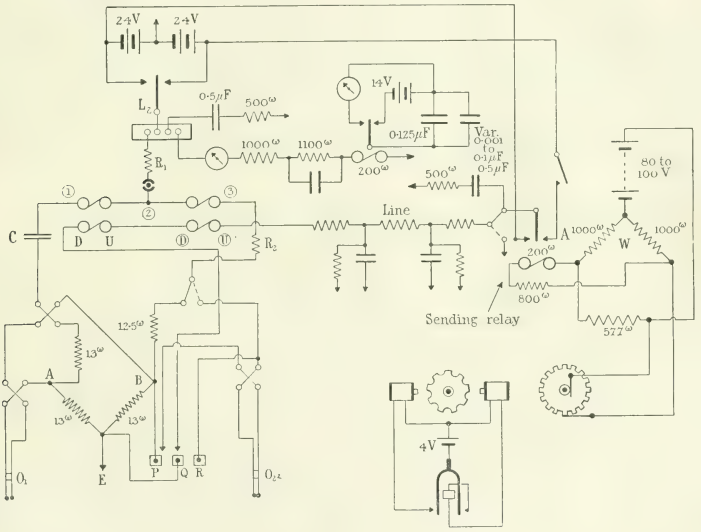

FIG. 6.

same as those already described for the auxiliary circuit tests. The plug contacts P, Q and R, are for changing the connections to the oscillograph.

It was expected that the rapid variation in the auxiliary currents would produce quite an appreciable effect in the line coils, and a test proved this to be the case. For this test the line circuit was completed through one vibrator of the oscillograph, but the voltage was disconnected so that only induced currents would be recorded.

The oscillogram, Fig. 7, shows the auxiliary components (upper curve), also the auxiliary resultant and the current induced in the line (lower curve). It will be

It should also be remembered that when the Gulstad relay is operated from an intermediate receiving relay, the local circuit of this relay will be of comparatively small resistance and the line circuit of the relay will act as the closed secondary of a transformer of which the auxiliary coils form the primary. Very considerable reaction then occurs and it is here suggested that the frequency of the Gulstad relay should in this case be adjusted with the local circuit of the intermediate relay closed but, of course, without voltage.

Fig. 8(*c*) shows the phase relation between the line current and receiver current. Fig. 8(*b*) shows the "squaring" of the wave-forms of the receiver current

when the auxiliary currents of the Gulstad relay are brought into operation, also the distortion of the line current by induction from the auxiliary.

Operation of the Line Currents.

When a lengthened current pulse is received for the formation of a dash or space (negative dash) the condenser current maintains the contact for about one-third of the length of the dash and then approaches a zero value. By this time, however, the line current will be approaching its full value, or will have reached it, and the resultant varies in the degree of control which it exercises in different parts of the dot signal. At the beginning of the dot it is equivalent to a sudden strong attraction of the armature, but towards the end it dies away, sometimes very gradually, as shown on the oscillograms. It is in this particular phase of the alternation that the relay is most sensitive to effects of the line currents. If the relay is running too quickly this sensitive phase will tend to occur too early (i.e. whilst the line pulse is still growing) and the signals will be distorted. On the other hand, if the relay is running too slowly the peak of the line pulse is displaced towards the peak of the resultant auxiliary current, and the initial part of the line pulse will assist the inductive branch current by the line current at the moment when the condenser is practically fully charged.

If the relay is vibrating in isochronism with the transmitter or in exact synchronism with the received pulses, the dots (positive and negative) will simply add their effects to those of the resultant auxiliary current, producing firmer contacts on each side. When the received currents are too weak to exert much control, fairly close synchronizing becomes necessary. With stronger signals some latitude is allowable. In this connection it should be observed that the auxiliary

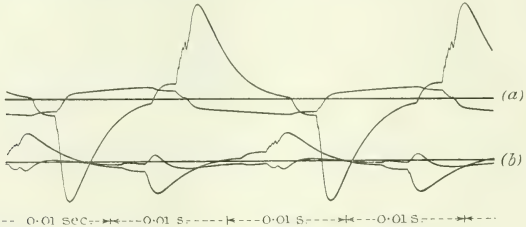

Fig. 7.—Auxiliary currents with receiver connected and line earthed at both ends. No voltage on line.
(a) Components. (b) Resultant and current induced in the line coils.

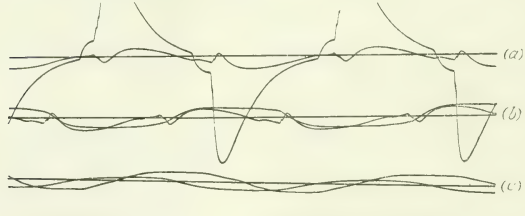

Fig. 8.
(a) Line current and condenser component. (b) Line current (auxiliary working) and receiver current.
(c) Line current (auxiliary disconnected) and receiver current. $R_1 = 100$; $R_2 = 1100$; $C = 10\,\mu F$.

continuation of the mark (or space) will depend upon this current. On a long circuit it may happen that at the moment when the condenser current has died away the line pulse has not reached its full strength, and the opposing current in the inductive branch will at once overbalance it, pulling the tongue away from the marking (or spacing) stop. Immediately the contact is broken the current in the inductive branch will fall a little (the oscillograms show a drop of about 1 mA in 1/4 000 second) and the growing line current now overbalances it and re-establishes the contact. The momentary break results in a split dash (or spurious dot). This effect can, of course, be prevented by increasing the resistance R_2, which keeps the opposing current below the value reached

and produce an earlier transit of the tongue, so keeping the relay in synchronism with the incoming signals. The phase relations of the line current and auxiliary resultant are shown in Fig. 9(*c*), the line current alone in Fig. 9(*a*). In Fig. 9(*b*) the auxiliary circuit is closed but without voltage.

When the relay is running too quickly the effect of a bias is considerably accentuated. For example, in a particular test a bias indicator was connected in leak to the tongue, and the bias to mark was adjusted to give a reading of 10° with only the auxiliary working. On joining up the line this reading increased at once to 30°. A spacing bias of 10° increased to 23° with the line working.

Considerable difficulty is met with at this point in the tests, owing to the fact that when a line current is sufficiently strong to give an appreciable deflection on the oscillograph it takes almost entire control of the relay unless the latter is very much mistuned. The author hopes, however, to resume the tests with some-what improved apparatus, when possibly some of the difficulties may be overcome.

a fairly heavy moving coil. The remaining terminals of the battery and meter are joined to the spacing and marking stops, respectively, of the relay. It will be seen that the vibration of the tongue produced by the alternating discharges through the relay coils alternately charges the condenser and discharges it through the milliammeter. The momentary pulses of current through the latter occur in one direction only but, owing to the inertia of the moving system, produce a steady deflection. The latter is proportional to the average or smoothed-out current, which is given by

$$i = nCV$$

where n = frequency in periods per second ;
C = capacity of the condenser ; and
V = voltage of the charging battery.

Since C and V are constant the deflection on the milliammeter is proportional to n, and the instrument can therefore be calibrated directly in periods per second or, if required, in words per minute.

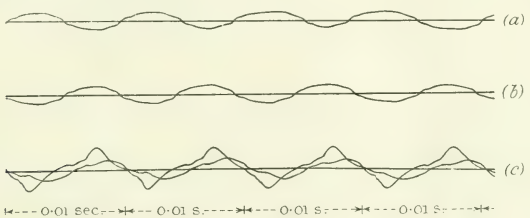

FIG. 9.

(*a*) Line current (dots) only. (*b*) Line current; auxiliary circuit closed without voltage. (*c*) Auxiliary resultant and line current.

FREQUENCY METER.

In the foregoing account of the experiments some considerable space has been given to the method of arranging the tests, as the author feels that the oscillograph as an instrument for telegraph tests has scarcely received hitherto the attention it deserves. Many problems too complicated to investigate satisfactorily mathematically could doubtless easily be investigated in this way. One further piece of apparatus may be here described. It was necessary to devise a form of direct-reading frequency meter for the tests which would work on intermittent currents or on ordinary a.c. waveforms, and for this purpose the following arrangement proved quite reliable and accurate. It would probably form a useful adjunct to any Gulstad receiving set. A sensitive relay set quite neutral has its coils connected through a suitable non-inductive resistance to the a.c. voltage of which the frequency is required. The tongue of the relay is connected to one terminal of a small condenser (capacity 0·125 μF) ; the other terminal of the condenser is joined on the one hand to a battery and on the other to a well-damped milliammeter with

The time-constant of the condenser discharge circuit must be small enough to allow the complete discharge to take place before the recharge occurs. With the apparatus used in the above tests the discharge was completed within approximately **1/1 000** second.

This form of meter works quite reliably on a.c. power circuits with any wave-form met with in actual practice. It possesses the advantage of being direct-reading, and if required can be arranged as a recording frequency meter for central station work.

In conclusion the author would like to express his warmest thanks to Mr. H. H. Harrison for his kindly interest and useful advice during the experiments, and to Prof. E. W. Marchant for placing at his disposal the oscillograph equipment and other resources of his laboratory.

APPENDIX.

CALCULATION OF TIME OF RISE OF THE CONDENSER CURRENT TO A MAXIMUM, WHICH DETERMINES THE "HOLDING-ON" EFFECT.

We neglect the relatively small current on the inductive branch.

Adopting the usual symbols and putting $R_1 + 100 = R$ we have

$$i = \frac{E}{R\sqrt{[1-(4L/CR^2)]}} \cdot \frac{e^{-tR/2L}}{2\sinh\,(tR/2L)\sqrt{[1-(4L/CR^2)]}} \quad \text{(i)}$$

or $i \times (\text{a constant}) = e^{k_1 t} - e^{k_2 t}$

where $k_1 = -R/2L + (R/2L)\sqrt{[1-(4L/CR^2)]}$

and $k_2 = -R/2L - (R/2L)\sqrt{[1-(4L/CR^2)]}$

For the maximum current we have, by differentiation,

$$0 = k_1 e^{k_1 t} - k_2 e^{k_2 t}$$

or $k_2/k_1 = e^{(k_1 - k_2)t}$

that is $t_{max.} = 1/(k_1 - k_2)\,\log_e\,(k_2/k_1)$.

In terms of the fundamental time-constants

$$T_1 = L/R, \quad T_2 = CR,$$

the equation may be written

$$t_{max.} = \frac{T_1}{\sqrt{[1-(4T_1/T_2)]}} \cdot 2{\cdot}3026 \log_{10} \frac{-1-\sqrt{[1-(4T_1/T_2)]}}{-1+\sqrt{[1-(4T_1/T_2)]}}$$

Since T_1/T_2 is in most cases small, we may neglect its square and higher powers and so obtain

$$t_{max.} = \frac{T_1 T_2}{T_2 - 2T_1} 2{\cdot}3026 \log_{10} \frac{T_2}{T_1} \quad \text{(ii)}$$

For a rough approximation we may put

$$t_{max.} = T_1 \times 2{\cdot}3 \times \log_{10}\,(T_2/T_1)$$

which gives $t_{max.}$ proportional to the logarithm of CR^2/L when R_1 is fixed.

To illustrate the numerical magnitudes involved we may apply Equation (ii) to the oscillogram shown in Fig. 3.

Here $R_1 = 200$, $L = 0{\cdot}048$ H, $C = 10\,\mu$F.

Hence $T_1 = 16 \times 10^{-5}$ second;

$T_2 = 300 \times 10^{-5}$ second; and

$$t_{max.} = 16 \times \frac{300}{268} \times 10^{-5} \times 2{\cdot}303 \times \log_{10} \frac{284}{16}$$

$$= 0{\cdot}00052 \text{ second.}$$

It is clear from Fig. 3 that the time-integral of the condenser current during the period of transit is only a very small fraction of that during the period of contact. Hence the effective voltage on the condenser at each make of contact is practically twice the applied voltage. E is therefore nearly 48 volts.

Discussion before the Liverpool Sub-Centre, 20 February, 1922.

Mr. T. E. Herbert: The Gulstad relay is being very extensively employed, and it has been found that on many circuits the speed of working has been practically doubled. For example, on the Liverpool–Edinburgh circuit, which was formerly worked by bridge duplex, it has been possible to revert to the differential principle, and to increase the speed of working from 80 to 150 words per minute. On the Liverpool–Aberdeen circuit bridge has been replaced by differential duplex working and the speed has been increased from 90 to over 120 words a minute; this circuit is, however, relayed at Glasgow. Telegraph circuits can be worked with the relay at a speed of 200 words a minute with a current of $\frac{1}{2}$ mA. The relay used by the Post Office is a Post Office standard "B" relay with additional windings. In some cases it is carried on a spring tray to obviate any deleterious effects due to external vibration. The author has emphasized the very interesting point that if the dashes and word-space signals only are received the relay does the rest of the work. The important points are, of course, that the transit time has been considerably reduced, and greater firmness of contact has been secured. The chattering effects noticeable in some of the oscillograms are very interesting. The oscillograph is used very extensively in the Research Section of the Post Office Engineering Department. As the result of one of these investigations many years ago it was found that there were three distinct breaks in the contact when signalling a dot, and that there was no difference in the behaviour of a Wheatstone transmitter with a jockey wheel and one with magnetic bias. It seems possible that some of the chattering observable at the receiving end, attributed to the Gulstad relay, was actually produced by the transmitting relay.

Professor E. W. Marchant: It was in 1898 that the relay was invented by Gulstad. He refused to patent it on the ground that his work had been done for the benefit of mankind, and it was not right that he should derive any financial benefit from it. Whatever one may think of Gulstad's social views, his wish to benefit mankind had the result that no manufacturer could get any guarantee that he would be protected in the manufacture of this apparatus against any other manufacturer who might wish to take it up. The result was that the practical development of the Gulstad relay was very seriously delayed. The very ingenious and simple bridge devised by the author for observing the differential effect of the two currents in the two branches of the relay circuit will be useful for other investigations. The variations in the frequency of the vibrations of the relay were very noticeable in the demonstration. Is it found in practice that there is any difficulty in maintaining synchronism at the two ends, or is the synchronizing effect of the signal sufficiently powerful to keep the tongues in synchronism?

Mr. C. E. Reeve: Professor Marchant asked a question about the balancing of speeds between the receiving and sending ends of a line, and I may perhaps explain the practice. The average number of reversals per foot of Wheatstone slip may be taken as 120. On the receiver slip take off 120 reversals from the Gulstad relay when the line coils alone are working. Next with the line coils cut out and the auxiliary coils of the Gulstad relay alone working adjust until 120 local reversals are obtained on the same length of receiver slip. Then the Gulstad relay and the distant Wheatstone transmitter are synchronous whatever the speed may be. I have not seen maintained on the Liverpool wires the high speeds mentioned by Mr. Herbert as resulting from the use of the Gulstad relay, but it has undoubtedly increased

the speeds of the circuits especially on underground and short submarine cables. Its advantages are important both to sound signals and also to the Morse signals as received on the Wheatstone receiver. There is no comparison between signals from the ordinary standard relay in bridge or differential working and the same signals received from a good Gulstad relay. I have not seen in Liverpool the case of a Gulstad relay working from an intermediate relay. In the author's opinion is it an advantage or otherwise to do away with the possibility of varying the distance of the armatures from, and the magnetic flux between, the two pole-pieces of the Gulstad relay? At present there is the opportunity of varying the distance. The Post Office type of Gulstad relay has the single position; there is no chance of variation.

Dr. S. S. Richardson (*in reply*): I think that only one point raised by Mr. Herbert is of a controversial nature, that is with regard to the chattering contact. Mr. Herbert suggested that this might be due to the sending relay rather than to the Gulstad relay, but this is not possible in the oscillograms taken, as the same chattering is found when the auxiliary circuits only are working. The chattering was simply due to the want of firmness of contact, just a little too much bias producing a slow transit of the tongue. I always find that a quick transit is followed by a firm "holding-on" effect. With regard to the corresponding kick of an ordinary relay, I have some interesting oscillograms which show the kick to be much more pronounced than the microscopic chattering of the Gulstad relay. I have never been able to get rid of this effect with an ordinary standard B relay.

With regard to Prof. Marchant's question relating to the steadiness of the running of the relay, my experience is that there is no difficulty in maintaining a perfectly steady run so long as the voltage of the battery is maintained. The variations noticed during the demonstration occurred only when the adjustments were being altered.

In reply to Mr. Reeve, I should say that it is a disadvantage to have the poles of the relay fixed. It is a great convenience to be able to adjust them for different rates of transmission.

SHORT-WAVE DIRECTIONAL WIRELESS TELEGRAPHY.

By C. S. Franklin.

(*Paper received 25th April, and read before the* Wireless Section *3rd May*, 1922.)

Directional wireless telegraphy is as old as the art itself, for Hertz made use of reflectors at the transmitting as well as the receiving ends in order to augment the effects, and to prove that the electric waves which he had discovered, obeyed, to a considerable degree, the ordinary optical laws of reflection. Senatore Marconi in his earliest endeavours to develop a telegraph system using electric waves, also employed reflectors to increase the range and get directional working.

The discovery by Marconi of the great increase of range obtained by the use of longer waves, and the earthed vertical aerial, practically stopped development on directional lines for the time being. The demand of the time was for increased ranges ; and as the first practical application of wireless telegraphy, namely, working to and between ships, required " all round " working there was very little call for directional systems.

To-day the range has arrived at the maximum possible on the earth, and the wave-length has increased to such an extent that the frequencies proposed are within or near to the limits of audibility. The possible gamut of wave-lengths is becoming very fully occupied, and although the development, during the past four years, of nearly pure continuous-wave transmitters, and of receivers with vastly improved selective powers has eased the problem, the time will soon arrive when the only way of increasing the number of possible services will be to employ systems having good directional characteristics.

There are, broadly, two general classes of directional aerial systems :

A. Those having the general characteristic that their directional power or polar curves are nearly independent of their dimensions. The directional result is obtained by opposing the effects of a number of aerials, or parts of an aerial with suitable phasing adjustments ; the degree of opposition being a function of the direction. Systems of this class may be made small compared with the wave-length employed ; for the purposes of position finding, and as receiving systems enabling interference to be eliminated from several directions, they have already been developed to a considerable degree. The simplest example of this class is the well-known frame aerial. By employing a sufficient number of aerials the system may, theoretically, be given any desired sharpness of directional power without making the dimensions large ; this can, however, only be done with a large sacrifice of receiving or radiating power.

B. Those having the general characteristic that their directional power or polar curves depend on their dimensions relative to the wave-length employed. In this class the directional result is obtained by adding the effect of a number of aerials, or parts of an aerial, when working in the required direction. The underlying principle is that the effects, for the required direction, are integrated over a wide front in proportion to the wave-length. Such systems can, therefore, only have small dimensions when using short waves, and this fact makes their development difficult.

As examples of such systems may be mentioned :—

(1) Reflector systems in general.
(2) Systems composed of lines of aerials, at right-angles to the working direction, correctly adjusted as regards phase. In this may be included the Alexanderson long aerial with its feeders.
(3) The Beverage long, horizontal receiving aerials. This aerial and equivalent arrangements form a class by themselves, but have the characteristic that the directional power is a function of the dimensions.

The reflector system was the first one that was tried for wireless telegraphy ; it has been considered by several investigators, but very little research work on such systems has yet been published. Useful research work on these lines is not easy ; the use of reflectors of reasonable dimensions implies very short waves of the order of a few metres. The very high attenuation of such waves over land or sea, and the difficulty of getting much power into them, tended to make early attempts very discouraging.

In this paper it is proposed to give some results of investigations made with reflectors and wave-lengths below 20 metres. It is also hoped to be able to give a demonstration with a continuous-wave valve transmitter furnishing approximately a 1-metre wave, and a reflector having a 2 wave-length aperture, so that some idea can be got of the order of the directional effect, or " beam," obtained.

The investigation was commenced by Senatore Marconi in Italy in 1916, with the idea of developing the use of very short waves, combined with reflectors, for certain war purposes. The author assisted him there, and it was very interesting work, as it was like being back in the very early days of wireless when one had a perfectly clear field.

The waves used were 2 metres and 3 metres. The only interference experienced with such waves is from motor boats and motor cars. These machines apparently emit waves from near 0 up to about 40 metres in length, and the day may come when they will have to have their ignition systems screened, as on some aeroplanes, or carry a Post Office licence for transmitting. Incidentally, if some of the motorists were to listen to

the irregularity of their ignition, they would be surprised. At Senatore Marconi's suggestion a coupled-circuit spark transmitter was developed, the primary having an air condenser and spark in compressed air. By this means a moderate amount of energy was obtained, and the small spark-gap in compressed air proved to have very low resistance. The decrement of the waves emitted was judged to be of the order of 0·03.

The receiver used was a carefully picked crystal, while the reflectors employed were made of a number of strips or wires tuned to the wave, arranged on a cylindrical parabola with the aerial at the focus. The transmitting system was arranged so that it could be revolved and the effects studied at the receiver.

one at the transmitter and one at the receiver, increased the working range about 3 times.

These Italian experiments showed that good directional working could be obtained with reflectors properly proportioned with respect to the wave-length. The attenuation over sea for the wave-length used was found to be very high, and with the apparatus available the maximum range obtained was 6 miles.

The experiments were continued at Carnarvon in 1917. With an improved compressed-air spark transmitter, a 3-metre wave and a reflector having an aperture of 2 wave-lengths, and a height of 1·5 wave-lengths, a range of over 20 miles was obtained to a receiver without a receiving reflector. The experiments at Carnarvon

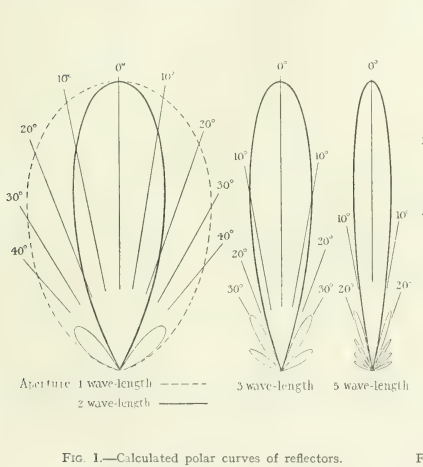

FIG. 1.—Calculated polar curves of reflectors.

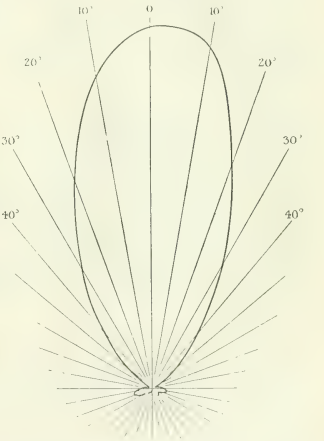

FIG. 2.—Polar curve of Hendon reflector: 28-metre aperture, 14·8-metre wave, measured on circle of 31-metre radius.

Assuming that the waves leave the reflector as plane waves of uniform intensity, having a width equal to the aperture of the reflector, it is not difficult to calculate the polar curve of radiation in the horizontal plane, which should be obtained from reflectors of various apertures. In Fig. 1 are shown the calculated curves for apertures of 1, 2, 3 and 5 wave-lengths.

The method of measurement at the receiver was the well-known "slide back" method with a rectifier; this method if calibrated against an adjustable local generator is quite reliable to a few per cent, and has given very consistent results.

Reflectors having apertures up to $3\frac{1}{2}$ wave-lengths were tested, and the measured polar curves agreed very well indeed with the theoretical curves. The use of two reflectors with apertures of $3\frac{1}{2}$ wave-lengths, brought into prominence a property of wave propagation which, the author thinks, is not generally known, and the extent of which is not realized. This is the very rapid increase in the strength of the electric field with height above the ground. The rate of increase appears to be a function of the height divided by wave-length, and, while not very noticeable with waves of several hundred metres, is very marked with waves of a few metres' length. The order of the effect may be gathered from the following experimental results.

It has been mentioned that the range attained at Carnarvon with a 3-metre wave was over 20 miles. The transmitter was at a height of 600 ft. and the receiver 300 ft., there being a clear air line between them. To the shores of Carnarvon Bay, 7 miles from the transmitter, there is also a perfectly clear air line,

yet the signals at sea level were much weaker than at 20 miles with the receiver 300 ft. up. It was not possible to ascribe the weakness of signals to any screening or reflections from trees or other objects. Tests were made at different levels on a hill situated at this point, and it was found that signals steadily increased in strength with height. Accurate measurements were not possible with the portable receiver, but the increase of strength of the field at a height of 10 wave-lengths was estimated to be 6 to 7 times. Further tests on this effect have shown that the increase of strength with height is not always uniform.

Subsequently, when this reflector and transmitter used at Carnarvon were brought down to sea level, it was found that the limiting range to the same receiver at sea level and over sea was 4 miles. When both transmitter and receiver are at a low level the range is very dependent on the nature of the intervening country, and is very restricted even over sea; when, however, both stations are many wave-lengths above the intervening country its nature is of far less importance, and the range is increased many times.

These experiments showed that very considerable ranges were possible with very short waves.

In 1919 experiments were commenced at Carnarvon with valve transmitters, with the idea of producing a directional telephone system. Mr. R. H. White and Mr. E. Green, and, later, Mr. A. W. Hall, assisted the author in this work. A wave of 15 metres was selected, which, while well within the capacity of the power valves available, allowed a simple reflector to be used without too large a structure. After some trials a single-valve transmitter was arrived at, taking about 200 watts with a 15-metre wave, and giving 1 ampere in the centre of a half-wave aerial. A heterodyne receiver with supersonic beat-note was employed.

After gaining some experience, and solving many small practical difficulties, very strong speech was obtained at Holyhead, 20 miles away. The strength was such that shadows produced by small hills and buildings were hardly noticeable, unless the stations were close behind them.

The next point was to test the maximum range, and particularly to find whether such waves would carry over the horizon, and whether there would then be a rapid falling off of strength. Permission was kindly given for a test to be made on the Dublin Steam Packet Company's boats running from Kingston to Dublin, and this was done in June, 1920. During this test, speech was received right into Kingstown Harbour, 70 nautical miles from Carnarvon, and the point was proved that there was no rapid diminution of strength after passing the horizon line from Carnarvon.

As a result of these experiments it was decided to test the range of a short-wave reflector system wholly over land. A site was chosen at Hendon, and a reflector and transmitter for 15-metre waves erected with the reflector pointing towards Birmingham. Tests were commenced in February, 1921, from Hendon to a portable receiver on a motor car. Very good speech was received up to 66 miles, and fair speech in the neighbourhood of Birmingham. A reflector station was then erected at Frankley near Birmingham, 97 miles from Hendon, and tests were started there in August, 1921. The following are some particulars of the Hendon and Birmingham plant.

The transmitter consists of two medium-size power valves working in parallel. The power to the valves is usually 700 watts (4 000 volts, 175 mA). The aerial is rather longer than half a wave-length, and has a radiation resistance of the order of 90 ohms. The efficiency, input to valves to aerial power, is between 50 and 60 per cent, and about 300 watts are actually radiated. With the reflectors up at both ends speech is strong, and of very good quality. It is usually strong enough to be just audible with a $\frac{1}{4}$ to $\frac{1}{2}$ ohm shunt across a 60-ohm telephone.

With both reflectors down the speech is usually only just audible with no shunt. Average measurements indicate that the energy received when both reflectors are up is about 200 times the energy received when not using the reflectors. Thus to get the same strength without reflectors as with them a 140-kW valve transmitter of the same efficiency would be required. Local measurements of the polar curves taken round the station show that the electric field in front of the station is increased approximately 4 times by the use of the reflector, and that the same order of increase is obtained during reception; the increase of energy received due to the use of the two reflectors should therefore be $4^2 \times 4^2 = 256$ times.

Fig. 2 shows a measured polar curve of the electric field of Hendon station taken locally. It is rather unsymmetrical owing, it is thought, to the ground being on a slope, and perhaps to local reflections from trees and wires.

It has been suggested that a polar curve taken locally round the station is not the same as the polar curve at a distance, and that the directional effect is soon lost. The author does not agree with this. It has therefore been planned to measure the range of Hendon and Birmingham in different directions, but this has not yet been done. The fact that by using reflectors the energy received at these stations is increased some 200 times is, the author considers, a proof that the directional effect does persist. It is, however, essential that the stations should be in situations free from obstacles which might cause powerful local reflections and distort the field. Experiments made with revolving reflectors, where it is comparatively easy to make measurements at any distance, also prove that the polar curve is practically constant at all ranges.

The production of waves of the order of about 12 metres and upwards is quite practicable up to several kilowatts by large power valves, and it is also practicable to operate valves in parallel. With such high frequencies very large currents pass into the grid and anode; the seals through the glass must, therefore, be large. The production of a reliable transmitting valve entailed a large amount of work, and the great dissimilarity of results from apparently similar valves was very puzzling for some time. In a new batch of valves the efficiency at 15-metre wave would vary from about 60 per cent down to 5 per cent, and if any attempt was made to push up the power on a bad valve the glass would promptly melt at some spot. The

cause of the trouble has been found to be due to losses in the deposits on the glass, owing to the high-frequency currents induced. Such deposits are always produced in valves during exhaustion, and vary considerably.

If a number of valves are laid successively between the plates of a small air condenser in a very high-frequency field of the order of 20 000 000 per sec. (without making any connections to the valves), the results are quite remarkable. Some produce no appreciable effect, while others at once put a big lead on the circuit, and, if 200 to 300 watts of high-frequency energy are available, the glass gets hot and will quickly melt at some spot. One of my assistants, Mr. E. Green, made a useful discovery which enables the loss due to this deposit to be avoided. It is now therefore possible to use what are practically standard valves, and their life appears to be about the same as for lower frequencies.

During the continuous-wave tests at Carnarvon it was found that reception was quite possible on the transmitting aerial while the transmitter was operating.

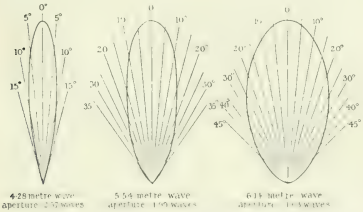

FIG. 3.—Polar curves for Inchkeith reflector: 5·5 metre parabola, 11-metre aperture, measured at 4 miles from transmitter.

This has been used successfully for duplexing between Hendon and Birmingham, and eliminates all switching.

The heterodyne may be either the transmitter, or an independent small heterodyne in the receiver. Both the transmission and the reception utilize the same aerial and reflector, and the transmitter is left going and can be operated while receiving.

There is no reduction in strength while the transmitter is on, but a practical trouble has appeared. Owing to the comparatively large power, strong currents are induced in all conducting structures and circuits close to the reflector and transmitter, such as the supporting towers and buildings, and every variable contact produces a noise. The elimination of all variable contacts in the neighbourhood of the transmitter has proved a work of some magnitude.

Reflectors, besides giving directional working and economizing power, are showing another unexpected advantage, which is probably common to all sharply directional systems. It has been noted that practically no distortion of speech occurs, such as is sometimes found with non-directional transmitters and receivers.

Although the results between Hendon and Birmingham constitute a record for telephony for ratio of range to wave-length—for such results were believed to be impossible two years ago—they are only a first attempt and do not represent the best that can now be done after the experience gained. Birmingham, it is interesting to note, is 10 400 wave-lengths from Hendon.

It has thus been demonstrated that wave-lengths of the order of 20 metres are quite capable of providing point-to-point directional commercial service over very considerable ranges. Such services will be comparatively secret as compared with the usual non-directional type of transmission.

The directional effect obtained with reflectors which are large compared with the wave-length, is so good that it was suggested that it would prove very useful for position finding for ships near dangerous points. Through the courtesy of Messrs. D. & C. Stevenson, Consulting Engineers to the Northern Lights, and the Commissioners of the Northern Lights, trials are being made with a revolving reflector erected on Inchkeith Island. Credit is due to the author's assistant, Mr. N.

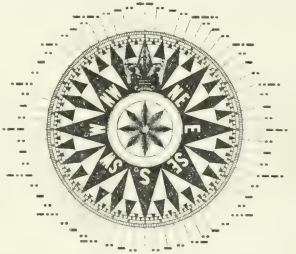

FIG. 4.

Wells, who has been superintending this work on the island—very often under strenuous conditions.

The general idea is that a transmitter and reflector revolving will act as a kind of wireless lighthouse. It is not intended at present for long ranges, but rather that revolving reflectors should be erected in position, similar to those at present occupied by fog signals, and be capable of similar ranges, so as to give the position to ships during fog when within about 10 miles of the danger point.

An experimental revolving reflector was erected on Inchkeith, and tests were made to s.s. "Pharos," the lighthouse tender of the Northern Lights Commissioners during the autumn of 1920. With a 4-metre wave, spark transmitter, a reflector of 8 metres' aperture, and a single valve receiver on the ship, a working range of 7 nautical miles was obtained. The reflector made a complete revolution once every 2 minutes, and a distinctive signal was sent every half-point of the compass. It was found that this enabled the bearing of the transmitter to be determined within $\frac{1}{2}$ point of the compass, or within 2·8 degrees.

These results were good, but it was desired to know the effect of putting the transmitter lower down at the point of the island where ships would pass quite near.

A new and larger reflector was designed, and its erection has just been completed.

Fig. 3 gives measured polar curves taken recently with the new reflector, and illustrates very well how the beam sharpens up with large ratio of reflector aperture to wave-length. The curves were measured at a distance of 4 miles.

The best method of giving the direction to a ship by means of such a revolving beam requires consideration. The method being adopted is, the author thinks, the most practical one. When listening in a receiver to a moderately sharp revolving beam the signals are heard only for a very short time. Take the case of such a beam as produced by the 4·28-metre wave: suppose it makes a complete revolution in one minute, then at 4 miles with the receiver at maximum sensitiveness signals will be heard for 7 seconds every minute. Near the limit of range, signals will be heard for only about 4 seconds. The exact time of maximum signals is not easy to determine by ear, but the times of starting and vanishing are easy to determine, as the rate of rise and fall of the signals is extremely rapid. The time half-way between these two times gives with great exactness the moment when the beam is pointing to the ship.

It would be quite possible to arrange to send a general broadcast signal when the beam passes through true north; then, by arranging for the beam to revolve at a perfectly uniform rate, the bearing on the ship could easily be determined by means of a stop-watch. This method is probably the most accurate, but has some disadvantages. It entails accurate timing mechanism at the transmitter; the use of two waves; and three, or perhaps four, receivers on the ship, as well as the use of a stop-watch.

For the short wave two receivers are required, one at each end of the bridge, or one fore and one aft. This is necessary to avoid screening by the ship itself. If the broadcast wave for giving the time when the beam passes true north is another short wave, then two more receivers would be required.

The method provisionally adopted avoids accurate timing mechanism at the transmitter and the use of a broadcast wave, also the use of additional receivers and a stop-watch. On the base of the revolving reflector contact-segments are arranged so that a definite signal is transmitted every half- or quarter-point of the compass. A distinctive letter is sent every two points, and short signs mark the intermediate points and half-points. When listening-in at the receiver a few short signs are heard and one or two letters. The letters and signs used are shown on the card. If the letters *t* (—) *i* (– –) *o* (— — —) *i* (– –) *t* (—) *i* (– –) are heard, by reference to the card the half-way position is between South and S. $\frac{1}{2}$ West and the bearing to the transmitter will be S. $\frac{1}{4}$ W. Fig. 4 gives the signs adopted.

The author will now try to give a demonstration with a 1-metre wave transmitter which has been made by Mr. Witt.

The apparatus proposed is of a very reliable nature. The spark transmitters are very robust, and last for years without attention. The receivers are simple valve rectifiers with fixed adjustments except for a "backing off" potentiometer for dealing with powerful signals at close range. The attenuation of these waves over sea is so strong that a little experience enables distance to be judged by strength of signals, and this can be measured by means of the potentiometer. The only qualification necessary for a person determining the bearing, is the ability to read a few Morse signs.

In conclusion, it is thought that enough has been done to show that short-wave directional wireless telegraphy is likely to be very useful in the future, and the results just described should lead the way to more extended researches.

The names of some of those who have been directly associated with these experiments have already been mentioned, and the author has to acknowledge the large amount of help and assistance derived from the advice and researches of many others.

Discussion before the Wireless Section, 3 May, 1922.

Senatore G. Marconi: I am very pleased that the author has called the attention of members to the important subject of the practical application of short-wave directional wireless, and to the way in which these waves may be controlled and directed by means of suitable reflectors. Short electric waves were the first with which I experimented in the very earliest stages of radio-telegraphy, and I might recall the fact that when, 26 years ago, I came to England, I was able to show the late Sir William Preece, then Engineer-in-Chief of the Post Office, the transmission of intelligible signals over distances of $1\frac{3}{4}$ miles utilizing short waves with reflectors, and only about half a mile by means of the elevated wire system. That, in view of later developments, appears to be very strange. The progress with the elevated wire system was so rapid, however, so spectacular and so comparatively easy, that it practically absorbed all attention and research as compared with the short-wave reflector system, and I am, therefore, glad that the author has again called attention to the fascinating possibilities of this method, which I might almost call another system of radio-telegraphy. Yesterday I talked to Birmingham from Hendon over the short-wave directional duplex telephone. The speech quality was very good and the communication easily equal to the average communication over trunk lines of the same length. Sir William Preece, to whose memory I shall always preserve the deepest sense of gratitude, first described my early tests with reflected waves at the meeting of the British Association in 1896, and afterwards at a Lecture which he delivered before the Royal Institution on the 4th June, 1897. On the 2nd March, 1899, I went into the matter more fully in a paper * which I read before this Institution, and to this paper I would recall the attention of members, as being of some historical interest. I am afraid very few, if

* *Journal I.E.E.*, 1899, vol. 28, p. 273.

any, who were present at the reading of that paper are here to-night. At that lecture I showed how a receiver would be actuated across the lecture hall and a bell rung, only when the beam of rays from a transmitting reflector was directed towards the receiver, and I also described tests carried out in transmitting a beam of reflected waves across country on Salisbury Plain, pointing out the utility of the system for lighthouses and lightships, in enabling ships to locate dangerous points around the coast. The matter there remained, and until my experiments in 1916, in which the present author took part, I do not think any further practical progress was made. Of the engineers of the Post Office and of the scientists who were present at those experiments on Salisbury Plain, one or two are here to-night. I might mention Admiral Sir Henry Jackson and Mr. H. R. Kempe, the latter of whom I regret not to see here. There were also present Mr. W. W. Bradfield and Mr. G. S. Kemp, of the Marconi Company, although Mr. G. S. Kemp at that time belonged to the Engineering Department of the Post Office. Mr. J. E. Taylor, of the Post Office, was also present at other experiments carried out by the Post Office at that time. The advent of continuous waves has now given a great impulse to the development and practical application of this short-wave directional system, and it must strike some of my friends as wonderful that means have now been devised for radiating continuous waves of as short a wave-length as 1 metre. Very many problems of great interest in regard to long-distance transmission with these waves have yet to be solved, and I believe that most people will agree with me that their study opens out a new and vast field of research. I hope that a great deal more work will be done in this direction and that this paper will serve the purpose of calling the attention of wireless workers to what may be considered to be a new field, although it was known so long ago. It is a new field so far as its present practical development has gone.

Mr. J. E. Taylor: This paper certainly deals with a highly interesting development in wireless telegraphy. I was with Senatore Marconi when he tried some of the very earliest of the experiments with wireless reflectors at the Post Office and from that day to this I have never lost sight of the possibilities of the reflector system of wireless telegraphy, mainly because it possesses that very great advantage of promising a much greater degree of secrecy for communication purposes than is attainable by any other system of wireless telegraphy with which I am acquainted. The idea that there is a field for the reflector system led me, in the very early days of the war, to take an opportunity of mentioning it as a promising field of development for use during the war for comparatively secret wireless telegraphy and telephony and for certain special purposes. That was in 1914. A year later I suggested to the Board of Invention and Research that this reflector method should be taken up, primarily in connection with communication from the ground to aeroplanes in flight. After due consideration the Board of Invention and Research came to the conclusion that the prospect of a successful issue of such experiments was not good enough to warrant steps being taken to develop it at that time. I confidently expect further developments in connection with the reflector system with even shorter waves than 1 metre, and I do not think there should be any insurmountable difficulties in achieving this. I rather look forward to the day when it will be possible to send beams of wireless waves in any desired direction and at the same time command a great deal of secrecy. In developments in that direction I have great faith in the reflector method being able to take the place of land lines for inland communications to a very considerable extent. I do not say that I anticipate that the time is near when the whole land-line system of the country will be superseded, but I have held the view for many years past that a development of this system would be sufficiently secret and practicable in its application to enable it to be used for communication between the minor towns and villages in the country and so save a lot of money on line-wire maintenance. Although it might appear at first sight as being a complicated sort of arrangement which requires a great deal of maintenance expenditure to keep it up, I feel that it has the capability of being reduced to something very simple; and although it has taken several hundred watts to transmit between Hendon and Birmingham, I think there are methods possible which would enable the same range of communication for either wireless telegraphy or telephony to be obtained with a fraction of that amount. I think, finally, that we have in this method a possibility of developing very short continuous waves which may be of some use for electro-medical purposes.

Major H. P. T. Lefroy: I feel the same interest in the author's remarks as one feels in hearing the adventures of an explorer who has visited a country with which one is not familiar but in which one is very interested. To appreciate fully his work, we must recognize that he has been using frequencies as much above those used in normal wireless telegraphy as the frequencies used in high-frequency line telegraphy at the other extreme are below them; in each case phenomena are obtained which are peculiar to those extremes of frequency and different from those of normal wireless, particularly as regards effective resistance. It is interesting to note the spiral advance in the art of wireless telegraphy. If we look back 35 years we find Hertz using the same wave-lengths as the author has been using; but if we now compare the ranges obtained then with the ranges obtained by the author, we find that the latter gets as many miles now as the former got yards then; the increase being due chiefly to the use now of triode receivers and triode transmitters. Historically, it may be of interest to know that in 1913 we arranged, at Aldershot, to carry out aircraft intercommunication for Fleet work by short waves. We got a Hertzian oscillator going on an airship, using spark transmission, by the end of that year, but the airships were then taken away and the work came to an end. The argument we used was that if very short ether waves, such as light or radiant heat, could pass effectively through the atmosphere for a very considerable distance, it was probable that very much longer ether waves then those, namely of 20 or 30 metres' length, would also be propagated very

well from one aircraft to another. We did not suggest using very short waves between the land and aircraft. The author has pointed out that the nearer we get to the surface of the earth the greater is the attenuation of these very short wave-lengths. Recently, somebody else has pointed out that he has obtained good results by the propagation of electric waves under the sea, provided the wave-length was as short as 1 metre. I have been wondering whether it is possible that the losses with these very short waves are chiefly surface losses at the boundary of two different media, rather than internal losses in the medium of propagation. If the author tried transmitting under the sea he might find that the deeper he got the better was the range. It seems from what he said about elevated transmission through the air that we were on the right lines in 1913, and that the use of very short waves is distinctly promising for aircraft work. It would be interesting to know what degree of amplification the author used in the experiments referred to. I presume he used a resistance amplifier. I should also like to know what the author considers to be the shortest wave that can be practically generated. From the point of view of range, may we take his value 10 000 wave-lengths as a rough working range-constant for waves from $\frac{1}{2}$ metre to 20 metres long? It was very interesting to hear what the author said about motor-car ignition systems radiating short waves. This should be of special interest in connection with aircraft, because of the jamming caused by their ignition systems, and it may suggest a line of thought concerning its elimination. On page 930 the author makes this statement:—"The time will soon arrive when the only way of increasing the number of possible services will be to employ systems having good directional characteristics." Concerning that, I think it would be of interest to all to mention here that I was privileged recently to hear of an invention which appears to me to be very important, and which, if it should succeed in practice as well as preliminary laboratory experiments indicate, will provide an entirely novel method of discriminating between wireless messages. If this expectation be realized, it will greatly increase the number of possible services in wireless telegraphy, and in that case the author's remark will not hold good.

Mr. A. Gray: I am glad to have the opportunity of congratulating the author on this part of the work he has done in the last few years. I had the privilege of being on board the "Pharos" when he made the tests on the Firth of Forth. Although it seems rather difficult to get a bearing, in actual practice it is very simple. The reflector keeps on turning round and an inexperienced observer gets the bearing letters for certain the second or third time even if he does not get them the first time. I have received a letter from Mr. D. A. Stevenson, the Consulting Engineer to the Northern Lighthouse Board, and with the Chairman's permission I should like to read part of it to the meeting.

Mr. Stevenson says:—"I am in receipt of your kind invitation to attend the meeting at the Institution of Electrical Engineers on the 3rd May and discuss Mr. Franklin's lecture on short-wave wireless. I regret very much that it is impossible for either my brother or myself to do so on account of business engagements. I regret this especially as I, as Engineer to the Commissioners of Northern Lighthouses, have long been looking to wireless for some help in our fog-signalling equipment and indeed carried out some experiments at an early date on the subject, but without success. I am, therefore, deeply interested in the success of the revolving reflector on which Mr. Franklin has been working as a fog-signal installation. The experiments I have already taken part in at Carnarvon and at Inchkeith were so promising that I have little doubt it will prove a great success. If the reflector does what I anticipate, it will, in my opinion, revolutionize our lighthouse fog-signal equipment. Our present sound fog-signals are the weak spot in our lighthouse equipment, as wind and "silent areas" render these signals on frequent occasions only audible at short distances and uncertain even at short ranges. Indeed, mariners have to be warned not to put too much confidence in them. The present system of getting bearings by calling up wireless stations and fixing the position by cross-bearings from these stations is no doubt of great service when vessels are some distance out at sea, but is of course of no use and inapplicable for a vessel closely hugging a headland or navigating an intricate channel, as it necessarily occupies some considerable time to get such bearings, and they cannot, therefore, be obtained from minute to minute as the vessel proceeds on her way. The wireless signals sent out by the reflector will, if successful, overcome these difficulties and give the sailor his bearings at once, continuously and, no matter what the wind and weather is, with almost the same accuracy as if the weather were clear and he saw the light. I have every confidence in the success of the reflector and I heartily congratulate the Marconi Company on the enterprise they have displayed in taking up the matter and Mr. Franklin on the ingenuity, skill and perseverance he has brought to bear on the subject."

Mr. R. E. H. Carpenter: The first thing which strikes me about this most interesting paper is the fact that, with the cylindrical parabolic reflectors employed, the reflected component of the wave-front would be very roughly cylindrical, the axis being horizontal, and I wonder, since the point obviously will have occurred to the author, that no mention is made of any attempt to confine the radiation in the vertical as well as in the horizontal plane by means of reflectors whose outline is that of a paraboloid of revolution. I quite realize that the radiator would not lie wholly in the focus, also the much greater difficulties of construction of such a reflector; they do not appear insurmountable, however, and it may well be that inaccuracies of figure would be made up for by the approach to a parallel beam, rather than one broadly divergent in the vertical plane. If the radiator were placed axially in such a reflector, the reflector bars being of course suitably rearranged, one would expect to find the electric force in the emergent wave-front radially polarized at every point, and it would be of interest to know whether such radiation, the mental picture of which is suggestive of a diagram of a vortex ring, would persist or whether diametrically opposite

parts of the wave-front, being in opposite phase, would simply cancel out. It would be of interest to know whether any interference effects have been noted close to the transmitter, due to interaction between the direct radiation and that reflected. The former, having a spherical wave-front, would presumably be of less importance at a distance, at any rate in line with the reflector. The production of comparatively powerful continuous oscillations giving rise to radiation of such wave-length as to make it susceptible of optical methods of control and investigation, and such that, by working across a valley, make it possible to experiment with radiation which, for the major part of its travel, does not approach within several wave-lengths of the ground, suggests that it would be of some theoretical interest to combine two of such dipole oscillators at right-angles, and excite them in quadrature, with the object of trying to produce a rotational wave. The clear air line between the stations would seem necessary since it would be likely that such a wave travelling near the ground would suffer much greater absorption of that component which is due to the horizontal oscillator than of that which is due to the vertical, so that a plane-polarized wave would be all that would be left at a distance. It is a little difficult to try to visualize the form of the electric flux of such radiation. Each line might perhaps be considered to have the form, at right-angles to the rotational radiator, of a sort of double-threaded cork-screw bent of one piece of wire, whose ends only closed on themselves at the conclusion of the wave-train.

Professor G. W. O. Howe: Before calling on the author to reply, I should like to make one or two remarks. One cannot but be struck with the enormous range of wave-lengths employed in radio-telegraphy. We have now actually employed waves of from 1 metre to about 30 000 metres in length, that is something of the order of 15 or 16 octaves, a much greater range than is covered either by the eye or by the ear. An interesting point in connection with the remarks which Senatore Marconi made is the fact that these early experiments that were tried and thrown on one side are being taken up again and put to practical account with the new apparatus and new facilities that are now available. Such a thing is rather calculated to make one investigate some of the earlier ideas that were discarded, with the object of seeing what can be done with them in the light of our modern knowledge and equipment. With regard to the point that the author made as to the strength of the field increasing vertically, I should be glad if he would give us a little more information about any exploration he has made as to the nature of the electric field near the earth's surface, because we know that these very short waves are very rapidly absorbed, so that in the immediate neighbourhood of the earth's surface the field must be rather complex. It would not be surprising if it were found that the maximum effect was got near the surface of the earth with an aerial held slantingly. I was very glad that the author said that he believed in the directional effects persisting with distance. There is one very simple case in which there is no doubt about the directional effects persisting with distance, apart from secondary interference, i.e. with two vertical aerials with the currents in opposite phases so as to give a figure-of-eight diagram. There can be no reason at all why there should ever be any signal in a direction at right-angles to the line joining the two aerials. Naturally, any field due to the current in the one aerial would be neutralized by the field due to the current in the other. If it is true for that case, it is not easy to see why it should not be true in other cases. The author made one remark for which I do not think he stated the reason. I do not know why there should be less distortion in the directional system than in the non-directional system of radio-telephony. The statement is made, but I do not think any reason is given for it. The paper covers such an enormous amount of research work and involves the consideration of so many difficulties that had to be overcome that, if time permitted, one could go on asking questions about it for a long time.

Commander J. A. Slee, R.N. (*communicated*): The aspect of the case as revealed by the work of the author which appeals very strongly to me, is the great assistance which can be given to navigators in thick weather by the application of the very short-wave directed beam. Regarded as an assistance to navigation, this directed beam can be used either as a leading or clearing mark, or as a rotating beam. When used in the former manner, any practicable degree of sharpness can be obtained by increasing the length of the sides of the reflector. This is a practical proposition because there is no need to rotate a leading or clearing mark, and therefore there is no disadvantage in prolonging the sides of the reflector. For navigational purposes it would be of great advantage if the real beam indicating the line of the channel, or passing over a danger to navigation, were flanked by two similar beams (of course transmitting different letters), so that any vessel wishing to pick up the main beam would get warning just before she passed into it, and also if she accidentally deviated from it the use of two flanking beams would tell her which side she had passed out of the channel. The idea of combining the telephone with a gramophone record for such purposes is, of course, very attractive; it is well known, however, that very much more power would be required to produce telephonic speech at a definite distance than is necessary for the purpose of telegraphic Morse, and, at any rate in the present state of the art, it is probably wisest to keep to the use of Morse letters for this purpose. When used as a revolving beam, the ingenious method of signalling a letter as the axis of the beam passes over each intermediate point of the compass, with easily recognizable symbols made at each intervening half-point, gives a method of determining bearings which is of sufficient accuracy for all pilotage work in close waters. The combination of the two methods of using these directed beams would very much reduce the possibilities of stranding, when it is necessary to navigate vessels in close waters in thick weather, although of course it does not reduce the risk which is the greatest of all under such conditions, that is to say, the risk of collision. It is much to be hoped that at an early stage, at least a national if not an international agreement will be come to, governing

the administrative details of the use of such a scheme. First of all, it should be decided whether the transmitters should be worked according to the points of the compass, or by tens of degrees. It should also be determined whether such bearing should be true or magnetic. This matter having been settled, it is equally important that the letters used should have the same meaning in all cases. Where it is possible that signals from two or more revolving-beam stations will be heard at the same time, or where they are near enough together for any doubt to exist as to the identity of the transmitting station, then a sufficient distinction can be made by varying the signs used between the letters indicating the bearings. If such an arrangement were made, the work of navigating in hazy weather would be very much simplified.

Mr. C. S. Franklin (*in reply*): I wish first to thank those who took part in the discussion for the interest and appreciation which they have shown, and I hope that the paper will have the effect of initiating further research. A great deal remains to be done before we can be certain what are the possibilities and the limitations of these short waves in combination with reflectors.

The remarks of Senatore Marconi do not call for any reply. His interest and early work in connection with short waves and reflectors are well known. The researches which have led to the results described in the paper were initiated by him in 1916 and it is to these and his encouragement that the present development is due.

I have to thank Messrs. Gray and Stevenson for much encouragement and assistance in connection with the development of the revolving beam, and I much appreciate their remarks. The use of revolving beams and of fixed beams (as outlined by Commander Slee) for the purpose of assisting navigation in hazy weather in dangerous and close waters is an application which I feel confident will develop considerably in the future. It is a field in which short-wave beams can render very considerable and effective service.

It may interest Mr. Taylor to know that the researches initiated in 1916 by Senatore Marconi on short electric waves were for war purposes, and at the time of the Armistice development had reached a practically useful stage.

In reply to Major Lefroy I have never attempted any transmission through water with very short electric waves, and I cannot say that I have any great hopes of success, but at some convenient opportunity I shall make a test. In the experiment at Carnarvon which showed the great increase of range obtained by elevating the transmitter and receiver, the receiver which gave good signals at 19 miles with a 3-metre wave was a simple rectifier and a single-valve low-frequency transformer amplifier. As regards the shortest electric wave that can be practically generated, I have produced one of 60 cm with a small valve associated with Lecher wire circuits, and I think this is near the limit at present for arrangements in which the circuits associated with the valve control the wave-length. Other investigators have, I believe, obtained waves shorter than this, using arrangements in which the wave-length is determined by the valve characteristic and the voltages applied, and not by the circuits associated. I anticipate that with improved valves designed for the work it will be possible to get 25-cm waves with a useful amount of energy.

With reference to Major Lefroy's criticism of the statement on page 930, I do not know what he has in mind; perhaps the remark is too dogmatic. Whatever discoveries may be made in the future there is no doubt that the development of systems having good directional characteristics will increase the number of possible services.

In reply to Mr. Carpenter, tests have been made with reflectors approximating to a paraboloid instead of a cylindrical parabola, and have given improved results. Very little has yet been done in this direction owing to the difficulties of constructing such reflectors of any size and also of measuring the concentration in the vertical plane. I have tried the experiment of combining two dipole oscillators at right-angles and exciting them in quadrature, and have produced a circularly polarized wave. I have also arranged a receiver coupled to two rods at right-angles to each other, and by phasing adjustments have been able to discriminate perfectly between a clockwise revolving wave and an anti-clockwise revolving wave. As Mr. Carpenter anticipates, it is necessary to have such a transmitter several wave-lengths above the ground, in order to preserve the rotational characteristic of the wave. Along the surface of the land or sea the component with its electric force horizontal is absorbed at a much greater rate than the component with its electric force vertical. Tests made with a 2-metre wave transmitter showed that the range when the wave was transmitted with its electric force horizontal was approximately $\frac{1}{10}$th of the range when the wave was transmited with its electric force vertical, the centre of the transmitter and receiver in each case being about one wave-length above the surface.

With reference to the points raised by Prof. Howe, I do not think that the weakening of the electric field near to the earth's surface can be explained simply as an inclination of the field to the vertical. It is true that generally the maximum effect is obtained near the surface with the aerial held slantingly, but the maximum strength so obtained is far less than the strength obtained several wave-lengths above the surface. As to why there should be less distortion with a directional system than with a non-directional system of wireless telephony, the observed facts are that with the 15-metre wave between Hendon and Birmingham no distortion occurs, while with longer waves and less directional effect distortion occurs. Distortion is assumed to be caused by direct waves and reflected waves arriving at the receiving station from different directions and producing interference effects which may be very different for slightly different wave-lengths. In this way certain components in the speech may be annulled and others magnified, thus producing distortion. The more directional the transmitter and receiver can be made, the less chance there is of any reflected waves arriving from other directions affecting the receiver, and therefore there is less chance of distortion. The subject is very controversial and I do not think that there is sufficient evidence to make a definite statement. I only submit that there is some evidence towards it.

A DYNAMIC MODEL OF TUNED ELECTRICAL CIRCUITS.

By Professor C. F. Jenkin, C.B.E., M.A., Member.

(*Paper received 11th April, and read before the* Wireless Section *7th June*, 1922.)

The use of dynamical models to represent electrical circuits often makes the behaviour of such circuits easier to understand or, at any rate, easier to visualize. The author when he began to play with wireless circuits found it difficult to realize the effects of each part of the complex circuit made up of the aerial and the tuning inductance and capacity, and, in particular, the effect of changing the coupling of the inductance and the capacity from series to parallel; he therefore attempted to make a dynamical model to represent the circuit. The model as finally arranged illustrates so many of the fundamental properties of oscillating circuits in a striking manner that it is thought a description of it will prove of interest.

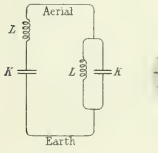

Fig. 1.

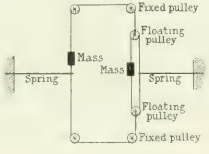

Fig. 2.

The essential thing in a dynamical model is that the mathematical equations for the motions of the various parts should be the same as those for the electrical circuit, and it is further desirable that the model should have some similarity of appearance to the electrical circuit so that its motion may be accepted by the mind as analogous to the behaviour of the electric circuit.

To make the mathematical equations the same it is well known that inductances may be represented by masses, capacities by springs, and resistances by friction (assumed to be proportional to velocity).

The electrical circuit is shown in Fig. 1, where the aerial is represented conventionally as an inductance in series with a capacity to earth.

The dynamic model is shown in Fig. 2. The inductances are represented by masses; the capacities by cantilever steel springs; the electric circuit by a *circuit* of string. The inductances may be varied by increasing or decreasing the masses, while the capacities may be varied by increasing or decreasing the length of the springs; these latter are fixed between wedges which may be put in at any point in their length. Quantities of electricity (coulombs) are represented by lengths of string; currents, by velocity of string; voltages, by forces. Thus the voltage across a condenser is represented by the difference of the tension of the string above and below the spring, and the charge by the deflection of the spring.

When the tuning condenser and reactance are connected in parallel, the corresponding mass and spring are connected side by side. When, on the other hand, the tuning condenser and reactance are connected in series, the mass and spring are connected in series (but a simpler change, having the same effect, is produced by inserting a wedge jamming one of the floating pulleys).

The behaviour of the model may be most easily followed by beginning with some simple examples.

Telephone engineers are familiar with the use of inductances and capacities in parallel for separating direct or low-frequency currents from high-frequency currents. Let the tuning capacity and inductance be connected in parallel as in Fig. 1, and then:—

(i) Apply a very low-frequency E.M.F. by moving the left-hand spring slowly up and down. The whole current will in this case flow through the coil; the right-hand spring does not deflect.

(ii) Apply a high frequency. In this case the whole current flows through the condenser; the right-hand mass is almost still.

(iii) Slowly reduce the frequency until the resonating periodicity is reached. Violent motion of mass and spring then results with hardly perceptible motion of the string representing the aerial, i.e. no current can flow in the aerial since a tuned circuit blocks the way. This experiment illustrates the use of a tuned inductance for coupling two valves: there is a high potential difference (string tension) across the combination.

Next consider the whole model. A few trials show that it has a natural period which it will maintain, the amplitude being reduced gradually by friction.

The natural period may be found from the equation:—

$$p^2\left\{\frac{L'}{K'}+\frac{L}{K'}+\frac{L'}{K}\right\}-LL'p^4-\frac{1}{KK'}=0,$$

where

L, L' are inductances or masses.

K, K' are capacities or deflections of springs per unit force.

$p=2\pi\nu=2\pi/T$. T periodic time.

This is a quadratic in p^2; there are therefore two natural periods. After making a few trials we hit on the second natural period. With the one natural periodicity the springs move up and down together; with the second natural periodicity the springs move in opposite ways.

Let the pulley next be wedged so that the mass is

now attached to the spring, that is, the inductance and capacity are in series. Again there is a natural period of vibration, which may be timed and compared with the former two. In this case both masses and both springs have the same motion and the period is the same as that calculated for a single spring with stiffness equal to the sum of the stiffnesses of the two and a mass equal to the sum of the two masses (or a single condenser of elastance equal to the sum of the elastances of the two and a single inductance equal to the sum of the two inductances).

To represent a Post Office aerial, the aerial spring must be made very short and its mass small. To tune the circuit to large wave-lengths a large loading mass is required; the natural period then becomes practically independent of the aerial capacity and inductance.

Discussion before the Wireless Section, 7 June, 1922.

Dr. J. H. Vincent: This device of the floating pulleys in entirely new to me. When the model has the two pulleys wedged it obeys exactly the same dynamical equations as the corresponding electrical model, but when the two pulleys are free a slight modification appears to me to be necessary. The actual displacement of the mass on the right requires correction. That can be seen at once from Figs. 1 and 2. If we make the right-hand spring infinitely stiff, we shall get no current and no motion of the spring on the right-hand side of the two floating pulleys, so that if we impose motion on the left mass there will be a corresponding motion of the two floating pulleys on the right-hand side, but, since the spring is infinitely stiff, the mass on the right-hand side will move twice as far as the mass on the left-hand side. The whole model certainly behaves qualitatively, in exactly the same way as the corresponding electrical system. Models are used a great deal in American elementary electrical engineering textbooks, and in order to avoid trouble with gravitation it is usual to run them on the flat and not vertically. In this way it is possible to remove the springs to illustrate the short-circuiting of the condensers. One dare not remove the springs in the case of the author's model.

Major A. G. Lee: I think the author's model illustrates the particular electric circuit in a better manner than any previous examples have done, and should be very useful in demonstrating to a class of students, to whom the mathematics of the subject may not always be clear or convincing. The circuit shown may be regarded as an elementary form of filter circuit, and it would be of great interest and utility if the mechanical model could be used to explore the questions of periodicities, amplitudes, etc., when damping is included. The natural periodicities of such a simple filter system, and others more complex, can easily be worked out mathematically if the resistances of the circuits are neglected, but the calculation of the periodicities and amplitudes becomes a very difficult problem if the resistance is included. I should therefore like to ask the author if he can take into account quantitatively the resistance in his mechanical model; and also whether it is possible to introduce the conceptions of weak coupling and insulation-resistance loss into the mechanical model.

Professor C. L. Fortescue: The author has pointed out that at one natural frequency the two masses move in opposite phases but at the other the masses move in the same phase. This is exactly analogous to the way in which the currents in the electric coupled circuits may be opposite in phase or in the same phase; so giving rise to a decrease or increase of the effective inductance with the corresponding increase or decrease of the natural frequency. The author's model represents a very tight coupling, but if a considerable proportion of the mass in the right-hand circuit is put in series with the condenser (spring) the behaviour of the model will represent the action of loosely coupled circuits. A model of this kind may be used to demonstrate shock effects if the friction can be reduced sufficiently, and I should like to ask the author whether he has attempted to ascertain the natural dampings and frequencies when the circuits are out of tune with one another and are subjected to a sudden shock.

Professor G. W. O. Howe: In 1916 I communicated to the Institution a paper * on the amplitude and phase of the higher harmonics in oscillograms and, as the mechanical equations of the oscillograph were less familiar to me, I employed an electrical analogy and deduced all the mechanical properties from the electrical equations, and in that way, to my mind, made the whole problem very much clearer. It is interesting to see that this paper deals with the reverse process, and makes the phenomena in the electrical circuits clearer by a mechanical analogy.

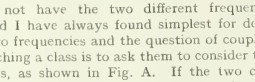

Fig A.

I quite agree with Professor Fortescue that this is essentially a system of two coupled circuits. We certainly have here two meshes coupled by means of a common inductance; were it not so, of course, we could not have the two different frequencies. The method I have always found simplest for dealing with the two frequencies and the question of coupled circuits in teaching a class is to ask them to consider two similar circuits, as shown in Fig. A. If the two circuits are opened and the two condensers are charged up in exactly the same way, and the two switches are simultaneously closed, obviously the effective inductance will be increased and each circuit will have a frequency of $1/[2\pi\sqrt{C(L+M)}]$. The system will have one frequency and there will be no beats. If, on the other hand, the condensers are charged originally in opposite directions, and the two circuits are simultaneously closed so that the currents are in opposition, each

* *Journal I.E.E.*, 1916, vol. 54, p. 19.

circuit acts as though it had a capacity C and an inductance $L-M$, and there is only a single oscillation present of that frequency. The ordinary arrangement is, of course, to have one condenser initially charged and the other uncharged. This case may be regarded as a superposition of the two cases considered above, and both the frequencies, viz. that corresponding to $(L+M)$ and that corresponding to $(L-M)$, will be present simultaneously. I am interested in the special form of mechanical analogy shown by the author,

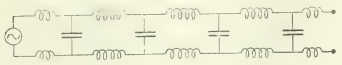

FIG. B.

because it very closely resembles the type which I thought of having made to illustrate the action of the various filters now being employed to pass only those currents having a frequency above or below a certain critical value. One type of filter is shown in Fig. B. Such a filter only passes to an appreciable extent those currents which have a frequency below a certain critical value. The mechanical model of this filter is shown in Fig. C. Alternating forces applied at X only cause appreciable oscillations at Y if the frequency is below a certain value depending

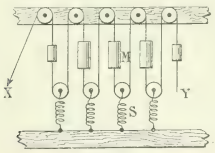

FIG. C.

on the masses M and the springs S. To make the analogy complete, the system should be duplicated below, the cord at Y returning via the lower system to the point X, any movement (current) in the one system being balanced by an equal and opposite return movement in the other.

Professor E. W. Marchant (*communicated*): About 9 years ago I made a very similar model for exhibiting the properties of coupled circuits, an account of which was published in the *Electrician* of 26 September, 1913. In my model the masses with their controlling springs, as used in the author's model, were replaced by two heavy pendulums, the period of which could be varied by altering the positions of the masses on the pendulum bars. One of the masses was above the point of support of each pendulum bar and one below, so that the period could be varied within wide limits. The coupling of the two circuits was effected by means of rubber cords passing around light aluminium pulleys, and the coupling was varied by using different thicknesses of connecting rubber cord. Attached to one of the pendulums was a brush which could be used to trace out on a piece of paper the oscillations of the pendulum. In this way a complete record was obtained of the motion of the pendulum. The model was intended primarily to demonstrate the effectiveness of the quenched-spark method of exciting the aerial. This was being discussed at considerable length at that time, and the advantage to be gained by tuning the secondary circuit with "shock" excitation was clearly demonstrated. I do not think that the author is able to vary the coupling between the two circuits in the model which he has described. Possibly it may be an advantage to introduce a rubber cord instead of an inelastic string to couple the vibrating masses.

Professor C. F. Jenkin (*in reply*): Dr. Vincent is right in saying that the motion of the string in the right-hand circuit is twice as fast as in the left. If inches of string in the main circuit correspond to coulombs, then in the right-hand circuit 2 inches of string will correspond to coulombs. With this convention the model is quantitatively correct. A horizontal model has points, but the friction is difficult to deal with.

It is not possible to take the friction into account as suggested by Major Lee.

I am much indebted to Prof. Fortescue for pointing out that the model represents a tightly coupled pair of circuits and that the coupling can be varied. I had not realized either fact before.

I sympathize with Prof. Howe's use of the electrical equations to solve mechanical problems. I have made the same use of them, but I think the mechanical model enables the actual occurrences to be more easily appreciated than the electric circuit, in which nothing can be seen.

I am interested to hear of Prof. Marchant's model. He will see from Prof. Fortescue's remarks that the coupling of my model can be varied. I do not think elastics could be used in my model; they would violate the circuital property of the current.

In conclusion I wish to thank the speakers for their kind appreciation of my model.

THE PERFORMANCE OF A RADIO-TELEGRAPHIC TRANSMITTER, WITH SPECIAL REFERENCE TO THE NEW INSTALLATION AT NORTH FORELAND.

By Norman Lea, B.Sc., Associate Member.

(*Paper received* 20*th May, and read before the* Wireless Section 7*th June*, 1922.)

Summary.

The paper deals with the performance of a commercial type of 1½-kW spark transmitter. The electrical quantities in the various circuits are discussed, and experimental results are given which enable a complete analysis of the losses to be arrived at. Particulars of the performance of this type of installation under traffic conditions show that the type of signal emitted gives high commercial efficiency.

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I. Introduction.
II. General description of the transmitter.
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IV. Power balance sheet.
V. Results under traffic conditions.
VI. Conclusion.

I. Introduction.

In making a survey of publications devoted to radio-telegraphic work, the dearth of information in connection with the detailed behaviour of transmitting apparatus becomes evident at once. This fact is to be deplored, not only because the matter is of some scientific interest, but also on account of the fact that the progress in this branch of applied science is such that a particular design may become embodied in a large number of installations.

Although the transmitter dealt with in this paper possesses many interesting features, it is only proposed to describe it in sufficient detail to render the results which will be quoted properly intelligible.

The actual transmitter on which the measurements were made was later installed at the Post Office station at North Foreland, and has now been in operation for nearly a year. Another set of the same type is now being installed at the Post Office station at Seaforth, near Liverpool, and, since many others have been fitted in ocean-going mail steamers, it will be realized that the results have more than a mere laboratory application.

II. General Description of the Transmitter.

The transmitter is designed primarily to handle traffic to and from ships at sea. It is capable of giving signals on any wave-length between 300 and 900 metres. Four working waves (usually 300, 450, 600 and 800 metres) are provided, any one of which may be brought into use by the operation of one hand-wheel.

Power is obtained from a motor-alternator of the two-bearing type having a frequency of 500 periods per sec. The output from this machine to the step-up transformer and primary high-frequency circuit is regulated by the adjustment of alternator excitation. Fixed tappings are provided on the alternator field regulator which correspond to full, half, and one-quarter power. A special form of synchronous spark-gap is mounted on the end of the machine and is fitted with a phase adjustment. A spark frequency of 1 000 per second is obtained by discharging the condenser once every half period, and this arrangement, of course, gives a note vastly superior to that obtained when using an alternator of lower frequency but with the same spark rate. The type of spark-gap employed has several important practical advantages over the stationary quenched gap sometimes employed. Some of these are :—

(1) The power may be changed without any re-adjustment of the gap whatsoever.
(2) The behaviour of the gap is sensibly the same whether it is hot or cold ; no time is wasted, and no outside stations are interfered with at the time of starting up.
(3) The note is clear and very penetrating.
(4) The efficiency is high, especially when judged by the only criterion which is of importance, namely, the ratio of power used to strength of signal received.

An emergency unit working on the Wilson principle is arranged to excite the same high-frequency circuits as are employed for power transmission. In the event of the main power supply failing, it is possible, therefore, to transmit on any one of the four waves without readjustment of tuning.

The general arrangement of the set and of the various details connected therewith will be best understood from the lantern slides.

III. Determination of the Losses.

When interpreting the results which follow, it is to be assumed, unless it is stated to the contrary, that the measurements refer to the conditions prevailing when transmitting on full power at 600 metres on an artificial aerial, and with the key depressed continuously.

(*a*) *Motor-alternator.*—The machine is of the two-bearing type with armature and rotor on the same spindle. Both stator and rotor are provided with windings, the former, which acts as the field, having 10 pairs of poles.

The losses were determined by the usual methods,

which need not be described. The figures are as follows :—

Total input (5·7 amperes at 480 volts) 2 730 watts.

Motor losses :

Armature (copper)	8·5 watts
Field (copper)	39·5 ,,
Iron, friction, windage of motor and alternator ..	415·0 ,,
Alternator losses :	
Rotor (copper)	6·5 ,,
Field (copper)	149·0 ,,
Iron	519·0 ,,
Total	1 137·5 watts

Motor efficiency = 83·2 per cent
Alternator efficiency = 70 per cent

(*b*) *Transformer.*—This is of the oil-cooled type wound for 500 periods per sec., the nominal voltages being 200 and 10 000 (R.M.S.).

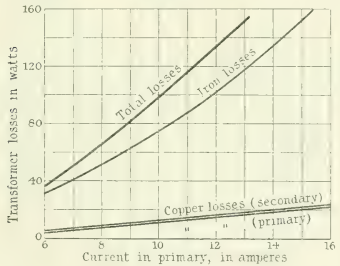


FIG. 1.

Copper losses at full power from the known resistances and currents are :—

Primary	12·2 watts
Secondary	18·8 ,,

The total losses were obtained by the Hopkinson method and are shown plotted for various currents in Fig. 1.

At full power we find :—

Iron (hysteresis plus eddy currents)	9·5 watts
Total losses	127·0 ,,
Efficiency	91·2 per cent

(*c*) *Low-frequency choke.*—This consists of a coil having a fixed number of turns wound on an iron core of the two-window type, but with an air-gap in the centre limb. The copper losses and total losses were measured by a wattmeter for various sine-wave currents. These results are plotted in Fig. 2.

At the full power load the losses are :—

Copper losses at working load ..	20 watts
Iron losses at working load ..	6 ,,
Total	26 watts

We now pass on to the H.T. side of the transformer where exact measurement becomes more difficult owing to the presence of high-frequency effects :—

(*d*) *Condenser of primary oscillatory circuit.*—This is

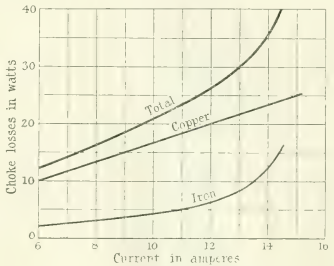


FIG. 2.

of fixed value (0·01 μF) and is of the multiple-section, mica-copper foil type, mounted in oil.

The losses in this are almost entirely due to the high-frequency discharge ; those due to the charging current at 500 periods per sec. may be neglected. The value of the losses was estimated by taking the temperature-rise at the end of a $\frac{1}{2}$-hour run at full power and comparing this with a curve (Fig. 3) of temperature-

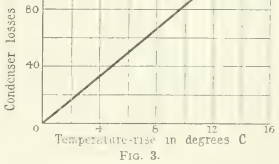


FIG. 3.

rises obtained by the use of a special heater placed inside the case. Oil was kept moving to ensure uniform results.

At the end of half an hour on full power with 600-metre high-frequency load, the temperature-rise was 4·0 deg. C., which, as may be seen from the curve, corresponds to a loss of 28 watts.

Since the high-frequency current at full power is

of the order of 70 amperes, the effective high-frequency resistance of the condenser is only 0·0057 ohm.

(*e*) *Main spark-gap.*—The only method which can be applied here is one involving equal temperature-rises. A thermometer was fixed to a convenient part of the spark-gap case, and great care taken not to disturb either the thermometer or lagging used in

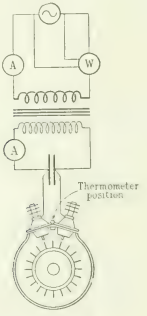


Fig. 4.

connection therewith. Two separate ½-hour runs at full power resulted in a temperature-rise (as indicated by this thermometer) of 46 deg. C. in each case.

An attempt was made to employ a heat-substitution method, that is, to use a heater consuming a known amount of direct-current energy; after several pre-

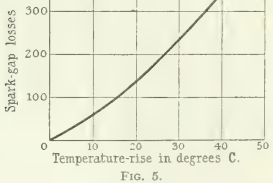


Fig. 5.

liminary trials, however, it was abandoned as unlikely to give a reliable result. The arrangement shown in Fig. 4 was therefore set up with a view to introducing the equivalent heating effect at the proper part of the gap, namely, at the electrodes. The leads from the condenser to the gap were kept very short and heavy so that the whole of the energy minus transformer and condenser losses, which had previously been determined, might be regarded as being dissipated in the gap. In this way a curve (Fig. 5) was developed giving the relation between watts turned into heat, and temperature-rise. Each point on the curve involved a ½-hour run at full power.

From an examination of results obtained in this way it appears that after making allowances for heat conducted to the gap from the machine windings, the spark-gap has a loss of 410 watts and a mean effective resistance of 0·084 ohm.

(*f*) The remaining parts of the primary circuit consist of comparatively low-resistance conductors, but the losses therein, as indicated by temperature-rise, are as follows:—

	Loss
Primary inductance (copper strip wound edgeways)	21·7 watts
Lead from condenser to switch (copper tube)	14·0 ,,
Lead from switch to inductance (heavy flexible)	7·0 ,,
Lead from inductance to switch	7·0 ,,
Leads from switch to spark-gap	14·0 ,,
Wave-change switch (estimated)	5·0 ,,
Change-over switch (estimated)	5·0 ,,
Total	73·7 watts

(*g*) *Artificial aerial.*—For test purposes an artificial aerial was employed consisting of a glass plate condenser in oil and having a capacity of 0·001 μF. The total length of lead including "aerial" and "earth" connections was 50 ft. The effective resistance of this arrangement was determined by inserting extra resistance of known values and noting the drop in aerial current when other conditions remained constant. Curves were then plotted showing the relation between the added resistance and the reciprocal of the aerial current.

It must be remembered that these changes in the aerial circuit will be reflected back into the primary circuit to an appreciable extent unless the coupling is weak.

If the coupling is at normal value, the primary current will not be constant and hence the energy induced into the aerial circuit will be variable, with the result that the measurement of aerial resistance will be inconclusive.

It is obvious that if the coupling be tightened we shall be approaching the conditions which apply to an ordinary transformer, where the resistance in the primary can be regarded as being replaced by a resistance in the secondary, and can be calculated if the square of the transformation ratio is used as a multiplier. In other words: with tight coupling any reading of aerial resistance by the method proposed will give a fictitiously high value.

Curves are shown in Fig. 6 for various couplings, and it is found that when the primary and secondary are 18 cm apart a reliable result is obtained. By drawing a tangent to the uppermost curve at the point corresponding to the test current, we find that the effective resistance of the condenser, aerial inductance, ammeters and 50 ft. of lead is about 9 ohms.

The aerial-earth resistance at North Foreland is

rather high on account of the chalky nature of the site. The full-power tests were, therefore, carried out with a series resistance which gave approximately the correct aerial current in order to imitate the actual working conditions.

IV. Power Balance Sheet.

Total power from mains, $5{\cdot}7 \times 480$			2 730
Losses in motor-alternator and field circuits.			
Motor: Armature copper	8·5		
Field	39·5		
Field regulator	11·0		
Total iron losses, windage and friction, including alternator	415·0		
	474·0		
Alternator: Rotor copper	6·5		
Field copper	149·0		
Field regulator	29·0		
Total iron losses	519·0		
Total motor-alternator losses	1 177·5		
Guard lamps	85		
	1 262·5		
Errors of experiment	37·5		
		1 300	
Wattmeter reading			1 430
Losses in transformer.			
Primary copper	13·2		
Secondary copper	18·8		
Iron	95·0		
	127·0		
Losses in choke.			
Copper	20		
Iron	6		
	26		
		153	
Balance (power input to high-frequency primary)			1 277
Losses in primary high-frequency circuit.			
Condenser	28		
Spark-gap	410		
Inductance	22		
Leads	42		
Switch contacts	10		
		512	
Balance transferred to aerial circuit			765

Losses in aerial circuit.

Added resistance, $6{\cdot}6^2 \times 8$	348
Aerial condenser, 2 aerial ammeters, aerial tuning inductance, coupling coil, 50 ft. earth wire, $6{\cdot}6^2 \times 9$	392
Losses unaccounted for	25
	765

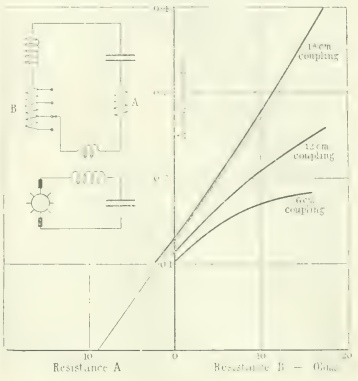


Fig. 6.

V. Results under Traffic Conditions.

As a result of tests extending over a period of two years, the reliable working ranges of the transmitter may be taken to be:—

By day $6\,H$ nautical miles
By night $15\,H$,, ,,

where H is the effective height of the transmitting aerial in feet. These figures are for cases where signals are received without high-frequency amplification.

VI. Conclusion.

In conclusion, the author would acknowledge his indebtedness to Mr. F. K. Crowther for his skill in making many of the necessary measurements and to the Radio Communication Company, Ltd., for permission to publish the results.

Discussion before the Wireless Section, 7 June, 1922.

Mr. N. Lea: I should like to supplement the paper by referring to the protection of motor-alternators. Many discussions have taken place with regard to the protection of machines against high-frequency discharges, and I think it may be of interest to show how the machines used for this transmitter are protected. The scheme adopted was to use condensers of the paper type connected across all windings, slip-rings, direct-current brushes and fields, and to earth the frame. The condensers have rather heavier insulation than is usual. It has been found that this type of device is far superior to any form of guard-lamp arrangement.

We found during tests that it was difficult to detect any protection given by guard lamps, but I am reminded that these appear in the power balance-sheet. We still employ some, but they are not used to protect the windings from high-frequency discharges; they are merely connected across the field of the machines to prevent a very large rise of pressure when the field circuit is broken. Tests with the protection device were carried out very exhaustively, and, in order to give an indication of crest voltages, we fitted safety spark-gaps (with paper in them, which was known to break down at a fixed voltage) across all the windings and to earth. We then tried to break down those spark-gaps by various means, chiefly by sparking with high-frequency discharge on to various parts of the set. The lantern slide shows heavy sparks about 2 inches long jumping from the lead connected to the aerial on to the frame, primary, commutator, slip-rings, fields, and about the terminal parts, etc. During this severe test the spark-gap insulation was adjusted so that it would break down at just under 1 000 volts (steady), and, since no breakdown occurred, it may be assumed that the protection afforded by the condensers was ample.

Professor C. L. Fortescue: A reference to the high-frequency portions of the balance-sheet shows that the rotary spark-gap is a high-frequency generator having an efficiency of the order of 75 per cent. A valve is usually regarded as being more efficient than a spark-gap, but either this view must be modified or the author's measurements must be inaccurate. In the latter connection it would be interesting to know what degree of accuracy is claimed for the high-frequency measurements. Some of the figures are rather surprising, particularly the low apparent resistance of the aerial tuning coil (about 1/4 000 ohm). The percentage coupling also is not stated and it would be interesting to know whether quenching contributes to the high efficiency. With regard to the losses on the low-frequency side, it may be remarked that the losses have been measured with sinusoidal currents, whereas the actual wave-forms differ greatly from sine waves. The method of describing the range of the station as so many times the height of the aerial appears simple and practical, but presumably the figures refer to the full output of the set irrespective of any limitations due to overloading the aerial.

Mr. E. H. Shaughnessy: I should like to refer to the method given by the author for calculating the working ranges of the transmitter and to the figure ($6H$) which he gives. If one takes North Foreland, with a mast height of 150 feet which, assuming an effective height of 50 per cent, is equivalent to 75 feet, his formula gives a range of 450 miles in daylight to ships, with a $1\frac{1}{2}$-kW set. I should not like to accept that as a fact; regular and steady commercial working would not be possible over that range. We should not guarantee a bigger range than 250 miles with such a set. The same remark applies to the formula of $15H$ given for night ranges. Niton station, which is smaller than that described by the author, is heard nearly every night, I believe, in Alexandria, which is about 2 000 miles away; but we should not be prepared to accept traffic on the assumption that the night range of the station is anything like 2 000 miles. Such distances cannot be regarded as practical ranges.

Mr. R. C. Clinker: I should like to know how the author separates the iron and copper losses shown in Figs. 1 and 2. In these figures the copper loss appears to give a straight line, when plotted against current. Should not copper losses be proportional to the square of the current? At the end of the balance sheet there is an item, "Losses unaccounted for, 25 watts." Does that include the radiated power? If it does not there cannot be any radiation, because the balance transferred is the same as the total loss. Has the author any data with regard to the radiation resistance of the aerial?

Major B. Binyon: I am glad that the author does not make any specific claims for efficiency. In much of the data that have been published on the subject of spark efficiencies one finds misleading statements; the shape of the resonance curve is often not taken into consideration, and one is led to believe that a set may have quite a high efficiency, when as a matter of fact from the point of view of performance under signalling conditions its range may be less than that of one which does not show such a high efficiency (primary input to aerial watts). I quite appreciate the conservative view which Mr. Shaughnessy takes with regard to ranges. Quite a number of ships, however, read his station regularly in the Mediterranean, which I think he will admit is more than 450 miles away, i.e. a greater distance than that which he thought was a rather optimistic range from the figures given by the author.

Mr. B. Mittell: I gather that the last speaker was referring to the quenched spark when he said that the calculated efficiency of some sets was greater than the efficiency which they gave in service. That fact was also brought out by the author, who stated that the only efficiency worth taking into consideration was the ratio of total power input to the signal strength received.

Professor G. W. O. Howe: It is to be regretted that there is no one present who is willing to act as a champion of the quenched-spark system and who will try, at any rate, to dispute some of the statements made in the paper or the inferences to be drawn from them. It is stated, for instance, that "The power may be changed without any readjustment of the gap whatsoever." This is presumably a reference to the quenched-spark system in which the number of gaps in series has to be changed in order to change the power. With reference to number (4) of the advantages given for the synchronous spark-gap, "The efficiency is high, especially when judged by the only criterion which is of importance, namely, the ratio of the power used to the strength of signal received," it would be interesting to have figures for other systems, similar to the $6H$ and $15H$ given in the paper, to enable an estimate to be formed of the relative efficiencies of the various systems by this criterion.

Mr. N. Lea (*in reply*): In reply to Professor Fortescue's question regarding the accuracies claimed for high-frequency measurements, I would state that, in view of the precautions taken, the figures are regarded as

being within about 10 per cent of the correct value. His remark with regard to the low apparent resistance of the aerial tuning inductance appears to have been made under a misapprehension, as no figure has been given for this part. The method of expressing range is probably only applicable to cases of a similar kind.

Mr. Clinker has pointed out a mistake which has occurred in tracing the drawings for Figs. 1 and 2. As a matter of fact the copper losses were measured at the full-load working points only, so that the obvious error does not affect the balance sheet in any way. No allowance has been made for radiated power as, in view of the closed nature of the circuit, it must have been small compared with the other quantities.

Mr. Shaughnessy thinks that the ranges quoted are excessive, but I would point out that the distances mentioned are being covered daily and therefore the performance is not a freak one. In drawing up the table, due allowance was made for " Operators' yarns " and only traffic figures were included. It is probable that the excellent " earth " conductivity, and conditions of wave propagations experienced at sea, account to a large extent for the more favourable ranges obtained.

UNVEILING AND DEDICATION OF THE I.E.E. WAR MEMORIAL.

The unveiling and dedication of the War Memorial in the Entrance Hall of the Institution Building in memory of the members of the Institution who lost their lives in the War of 1914–18 took place on Wednesday afternoon, 28th June, 1922. The Memorial is in the form of two bronze panels* containing the names of the fallen members and fixed respectively on the East and West walls of the Entrance Hall.

The cost of the panels was provided out of a fund collected from the members of the Institution by a committee consisting of Mr. C. H. Wordingham (*Chairman*), Mr. Ll. B. Atkinson, Mr. W. A. Chamen, Mr. R. A. Chattock, Dr. S. Z. de Ferranti, Mr. J. S. Highfield, Mr. A. Jacob, Lt.-Col. W. A. J. O'Meara, C.M.G., Mr. G. W. Partridge, Mr. H. Scholey, Mr. S. Sharp, Mr. A. M. Sillar, Mr. Roger T. Smith, Mr. A. P. Trotter and Mr. W. B. Woodhouse.

The space in the Entrance Hall near the Memorial was reserved for the relatives of those in whose memory the Memorial has been erected, the members, other than relatives, being accommodated in the Lecture Theatre. While the audience was assembling, sacred music was performed by a section of the Band of the Royal Engineers, Chatham.

The first part of the ceremony took place in the Lecture Theatre, where the hymn "O God, Our Help in Ages Past" was sung, the singing which was accompanied by the Band, being led by choristers of the H.M. Chapel Royal, Savoy, under the direction of Dr. Bromley Derry, Director of Music.

The Rt. Rev. Bishop Ryle, K.C.V.O., D.D. (Dean of Westminster), having led the assembly in the Lord's Prayer, recited the following prayers :—

"O God, and Father of our Lord Jesus Christ, who gave Himself a ransom for many and laid down His life for others, we remember before Thee with thanksgiving all Thy servants who have fought and fallen for the honour of their country, and especially those members of the Institution of Electrical Engineers, whose obedience unto death we commemorate this day. Have them, we beseech Thee, in Thy Holy Keeping, that while their bodies lie in the dust their souls may be with Thee. Grant to them, and to us and all the faithful, a merciful judgment at the last, and make us all glad with the joy of Thy Countenance in the Eternal day; through Jesus Christ our Lord. Amen."

"O Lord Jesus Christ, who didst for us endure the Cross, and didst thereby redeem us unto God, grant unto us that, saved by so great a deliverance, we may take up our cross and follow Thee in patience and all humility of mind. Look upon us and upon this land for which our brethern strove and died, and pour out upon us the spirit of love and service and goodwill, that we may bear one another's burdens, and may so fulfil Thy law that our lives may be well pleasing in Thy sight, who livest and reignest with the Father and the Holy Ghost, ever one God, world without end. Amen."

Bishop Ryle, Air Chief Marshal Sir H. M. Trenchard, Bart., K.C.B., D.S.O., the President (Mr. J. S. Highfield), the Senior Vice-President (Dr. W. H. Eccles, F.R.S.), the Members of Council and the Secretary then proceeded to the Entrance Hall, where Sir H. M. Trenchard delivered the following Address :—

Sir H. M. Trenchard: This Memorial which I am about to unveil will surely remain a never-forgotten token of the honour in which their fellow-citizens hold the memory of the Gallant Dead. Over two thousand members of this Institution were on active service in the Great War. Apart from these, most of its other members were engaged in the production of electric machinery and power for the supply of munitions. Of those on active service, 162 lost their lives. Over 500 War decorations were awarded to members of the Institution. Between the middle of September and the middle of October 1914, the Institution, in conjunction with the Institutions of Civil and Mechanical Engineers, recruited 670 engineers, the full complement required for the Engineer Units of the Royal Naval Division. May this memorial stand as a signpost for future generations, pointing out the path of duty and of patriotism so nobly followed by those of their profession who went before them. I will now order this Memorial to be unveiled in memory of the members of the Institution of Electrical Engineers who gave their lives for their King and Country in the Great War, 1914–1918.

The Memorial was then unveiled, the tablet on the West wall by the President (Mr. J. S. Highfield) and that on the East wall by the Senior Vice-President (Dr. W. H. Eccles, F.R.S.).

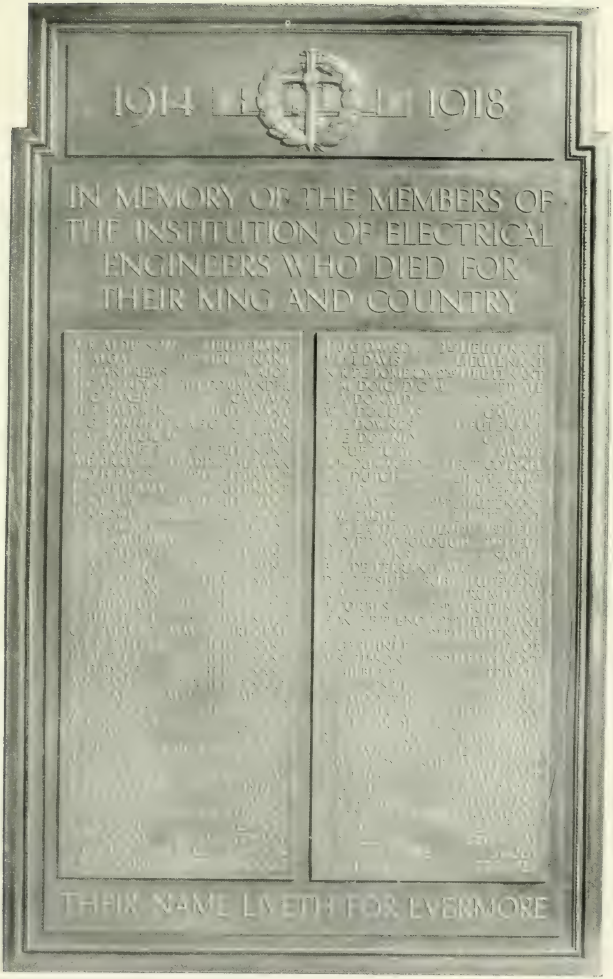
After which **Bishop Ryle** dedicated the Memorial with the following prayer :—

"In the faith of Jesus Christ we dedicate these Memorials to the glory of God and in proud and thankful memory of those members of this Institution who laid down their lives for their King and for their Country, in the name of the Father, and of the Son, and of the Holy Ghost. Amen."

The Blessing was then pronounced by the Dean of Westminster; and the Last Post and the Réveillé having been sounded by trumpeters from the Band of the Royal Engineers, Chatham, the ceremony terminated with the singing of the National Anthem.

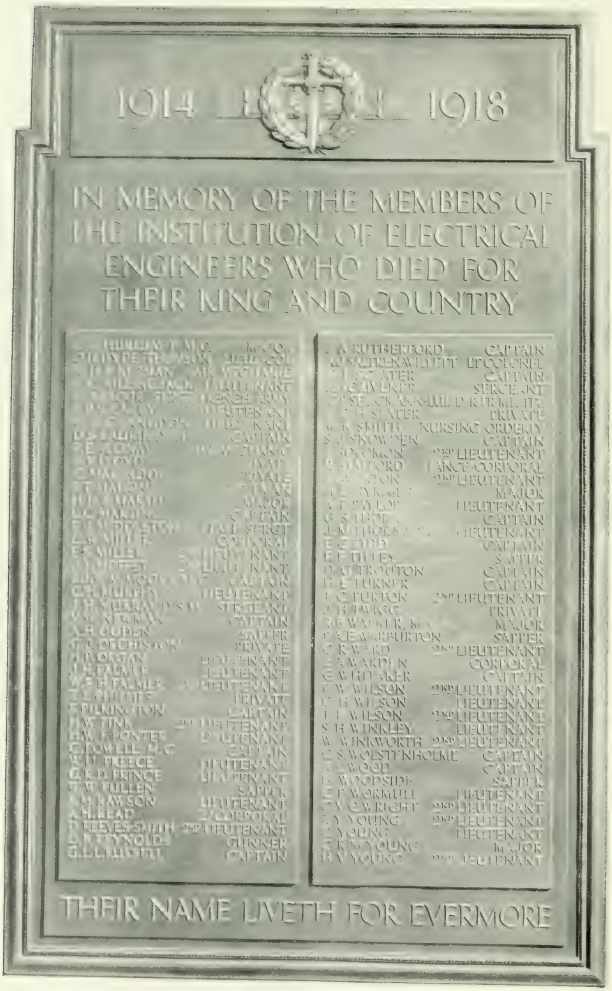
The following acted as stewards: Major B. Binyon, O.B.E., R.A.F., Lt.-Commander J. K. Catterson-Smith, R.N.V.R., Major K. Edgcumbe, L.E.E., Lt.-Col. F. A. Cortez Leigh, T.D., R.E., Major T. Vincent Smith, M.C., R.A.F., and Captain T. H. Roberts Wray, O.B.E., R.N.V.R.

* Reproductions of these panels will be found facing pages 948 and 949.


1914 1918
IN MEMORY OF THE MEMBERS OF THE INSTITUTION OF ELECTRICAL ENGINEERS WHO DIED FOR THEIR KING AND COUNTRY
THEIR NAME LIVETH FOR EVERMORE

I.E.E. WAR MEMORIAL PANEL.
(West Wall of Entrance Hall.)

P.T.O.



I,E,E. WAR MEMORIAL PANEL.
(East Wall of Entrance Hall.)

OBITUARY NOTICES.

ALEXANDER GRAHAM BELL, LL.D, Ph. D., D.Sc., who first joined the Institution in 1877 as a Member and was elected an Honorary Member in 1913, died on Wednesday, 2nd August, 1922, at the age of seventy-five, at his summer home in Nova Scotia, near Baddeck. He was buried on 4th August, at sunset, on the summit of a mountain overlooking the Bras d'Or Lakes. The manifold activities of his life, devoted to the service of mankind, would require volumes to portray. The medals and other honours which he received from learned societies, his honorary degrees from universities at home and abroad, and special recognition by Governments, all testify to the esteem in which he was held. His scientific researches in the field of heredity and eugenics, his experiments in aeronautics, his work in improving the phonograph and in teaching the dumb to talk, and his invention of the photophone, reveal the scope of his mind. This record alone is enough to ensure his fame, but his fundamental discovery of the method of transmitting articulate speech by electricity, and his invention of the apparatus to do this, have placed his name among the immortals.

Dr. Bell was born on 3rd March, 1847, in Edinburgh, Scotland. He went to Canada in 1870; and the next year, at the age of twenty-four, he removed to Boston. After introducing into New England schools improved methods of teaching deaf-mutes to speak, he was appointed a professor in the School of Oratory of Boston University. In his spare time he conducted experimental researches in electrical wave transmission. He was assisted financially in these experiments by two gentlemen of Boston, Thomas Sanders and Gardiner Greene Hubbard. By the summer of 1874, he had worked out his fundamental theory that the successful transmission of speech by electricity could be accomplished by producing "electrical undulations similar in form to the vibrations of the air" which accompany the original words or sounds. In spite of great difficulties and discouragements, he succeeded in reducing his theory to practical form, when at Boston, in the summer of 1875, he invented a telephone which faintly transmitted parts of words and even entire words. Mr. Thomas A. Watson, Bell's assistant, relates that it was on 10th March, 1876, over a line extending between two rooms in a building at No. 5, Exeter-place, Boston, that the first complete sentence was ever spoken and heard through the electrical telephone. It was spoken by Bell and heard by Watson, who recorded it in his note book at the time. It consisted of these words: "Mr. Watson, come here; I want you." Thus the telephone was born. After completing his fundamental invention, Bell in a remarkable document predicted with amazing foresight the telephone, system of the future. He also invented the photophone, which was the first method of transmitting speech by electricity without wires, and the induction balance and telephone probe for which he was awarded the honorary degree of Doctor of Medicine by the University of Heidelberg. To his successors in the laboratories in which he was the original worker, he left the further conduct of telephone research and development.

Turning to other departments of science, he displayed his remarkable intellectual gifts by the fruitful researches which he conducted In his work on behalf of the deaf, which he continued to the end, is revealed a dominant motive in his life.

To Bell was accorded a privilege so often denied to those who have advanced the world by their discoveries—he lived to see the triumph of his great idea. When the first sentence was transmitted, the public regarded the telephone as a mere toy. Then, the telephone plant of the entire world could be carried in the arms of a child. To-day, vast telephone systems of intercommunication have been developed, extending the spoken word among the peoples of the nations. The advances of the telephone art made by the successors of Bell were always a source of great satisfaction to him. Some of these, epoch-making in their nature, gave him special gratification. On 25th January, 1915, the transcontinental line spanning Bell's adopted country from ocean to ocean was, in the presence of dignitaries of state and nation, dedicated to the public service. This was a day of triumph for Bell, for, using a reproduction of the original instrument, he once again spoke the memorable words: "Mr. Watson, come here; I want you." But this time Bell was at New York, and Watson who heard him with perfect ease, was 3 000 miles away in San Francisco. Another advance attained the greatest distance over which the transmission of speech had ever been achieved. Early in the morning of 30th September, 1915, words were spoken through a radio telephone at Arlington, Virginia, to the Hawaiian Islands where they were plainly heard. But, as if to proclaim the telephonic conquest of time as well as space, the words reached these distant islands of the Pacific when it was there still the evening of 29th September. There yet remained to be realized that prophetic dream of the early telephonists—the bridging of the Atlantic by the human voice. But the day of its fulfilment was not far off, for on 21st October, 1915, during the dark days of the war, speech was for the first time in history successfully transmitted across the Atlantic Ocean. This was accomplished by the radio telephone, which carried the words spoken at Arlington, to the Eiffel Tower at Paris.

The last memorable telephone development destined to occur in the life of Bell will always be associated with a great historic occasion. At the burial of the Unknown Soldier at Arlington, on 11th November, 1921, the voice of President Harding, by means of the new loud-speaking amplifiers, was easily heard by the great concourse of a hundred thousand people about him, even by those in the most distant parts of the vast cemetery. Corresponding multitudes numbered

by tens of thousands, at New York and San Francisco heard over the wires every word spoken by their Chief Magistrate, as clearly as though in his actual presence. These distant multitudes heard also the invocation of the Chaplain, the music and the hymns, and the words of the commitment service used by the Bishop at the grave. They joined with each other and with those at the cemetery in the singing of the hymns, and they united with the President in reciting The Lord's Prayer with which he closed his address. They heard in amazement the salvos of artillery fired at the grave, and even those on the shores of the Pacific caught the loud reverberations thrown back by the Virginian hills. At the end, in profound silence and with heads bowed in sorrow, they listened to the plaintive notes of the trumpet sounding the soldiers' last farewell.

On that day, the achievements of science imparted a mystical power to the most solemn national ceremony in the history of America. This ceremony, its deep significance so enriched by the art of Bell, we can now believe contained an exalted sanction of the greatest of all the achievements of his life.

JOHN J. CARTY.

ERNEST ALEXANDER CLAREMONT was born in 1863, the sixth son of Dr. Claude Clarke Claremont of St. Pancras, London. He received a technical education, specializing in electricity, and was apprenticed to one of the early electric light companies. When quite young he started in business with Mr. F. H. Royce, a company known as F. H. Royce and Co., Ltd., being very shortly afterwards formed to develop the business, which was subsequently reorganized and is now Royce Ltd. of Trafford Park, specializing in electric cranes. Mr. Claremont remained to the last one of its managing directors. In the early part of this century this company took up the manufacture of motor cars. The late Mr. C. S. Rolls associated himself with it and in 1906 a company, now the famous Rolls Royce, Ltd., was formed to take over this department. Mr. Claremont became, and remained until August 1921 (when he retired on account of failing health), Chairman of the Board. About 20 years ago he accepted an invitation to join the Board of Messrs. W. T. Glover and Co., Ltd., and was shortly afterwards made Managing Director of that company, holding that position until his retirement, when he was appointed Chairman of the Board. He died on the 4th April, 1922. He was elected a Member of the Institution in 1897, and in 1900 served on the Committee of the Manchester Local Section, now the North-Western Centre. A. W. C.

JAMES HALLY CRAIG was born in Glasgow in 1860, and received his general education at Glasgow Academy, Dollar Academy, and King's College School, London. After a few years spent in the shipbroking business, and then as an accountant and auditor in London, Dublin and Glasgow, his natural bent for engineering led him to study the theoretical side of the subject at the Glasgow Technical College, and he subsequently became joint managing director of Messrs. Norman and Son, Ltd., Glasgow, now Messrs. Claud Hamilton, Ltd. A desire for wider experience sent him to America where after varied practical work, chiefly on electric construction in mines in the Western States, he became New England manager for the Crocker-Wheeler Company, with headquarters at Boston. In 1892 he was given plans for an electric vehicle which were brought from England, and he supervised and designed the electric equipment of what was believed to be the first electric vehicle in the United States. While the adventurous spirit was strong he joined the 8th Massachusetts Rifle Brigade, and was soon promoted to a Captain. He saw active service in the Spanish-American and Cuban wars. Returning from America to join the staff of the British Westinghouse Company, he was first stationed at Manchester, and then became manager of the Birmingham district office. For a few years he was manager for Scotland for the A.E.G. Company, leaving this firm in 1912 in order to start business on his own account on the commercial side of electrical engineering. While in Boston he was one of the founders of the Boston Athletic Club, and was an adept at rowing. He also, when in Ireland, was very successful in races on high bicycles. His all-round sportmanship won him many friends, and curling, shooting, fishing and yachting, golf and bowls were all in his athletic sphere. He died at Glasgow on the 22nd July, 1922, and will be missed by a large circle of friends. He was elected a Member of the Institution in 1907. J. A. O.

SIR CHARLES DOUGLAS FOX, K.B., J.P., was born on the 14th May, 1840, at Smethwick, Birmingham, and died on the 13th November, 1921, in London. He was the eldest surviving son of the late Sir Charles Fox who designed and constructed the first Exhibition of 1851 in Hyde Park. He was educated at Cholmondeley School, Highgate, King's College School and King's College, London, of the last-named of which he was a Fellow. With his brother, Mr. Francis Fox (now Sir Francis Fox), he was articled to his father in 1858, and in 1860 joined him, the firm being known as Sir Charles Fox and Sons. On the death of Sir Charles Fox, the title of the firm was changed to Sir Douglas Fox and Partners. The firm have acted as engineers-in-chief and consulting engineers to many important undertakings, both at home and abroad, amongst which may be mentioned the construction of the London, Chatham and Dover and London, Brighton and South Coast Railway approaches to London. Sir Douglas was constantly engaged as an expert engineering witness in the Parliamentary Committee rooms at Westminster, in connection with the promotion of and opposition to Bills for the construction of railways and harbours, etc., and London tube railways. He was elected a Member of the Institution in 1902, and was also a Member of the Institution of Civil Engineers, serving as President of that Institution in 1899–1900, and also for many years on the Engineering Standardization Committee. He was an Honorary Member of the American Society of Civil Engineers. He was deeply interested in all Christian and philanthropic work.

WILLIAM BERNARD GODFREY, whose death took place on the 27th July, 1922, at Hindhead at the

age of 68, was the youngest son of Joseph Sylvester Godfrey of the Middle Temple and was educated at Winchester College. After serving his apprenticeship with Messrs. Quick and Son, he acted in 1876 and 1877 as assistant engineer in the construction of the first steam tramways in Paris, and from 1878 to 1880 was engaged in the erection for the Lontin Electric Light Company of some of the first public electric lighting installations in London, notably at the old Gaiety Theatre and Her Majesty's Opera House and Aldersgate-street Station. In 1881 he became a partner with Mr. Everard Hesketh in the very old established engineering works of Messrs J. & E. Hall, Ltd., at Dartford. The firm specialized in the manufacture of refrigerating machinery and was engaged from the earliest days of such installations in the fitting out of ships for the importation of frozen meat. In 1888 the late Mr. Alexander Marcet joined the firm and after much experimenting the CO_2 refrigerating machine was developed into the practical machine as it exists to-day. When the present company was formed in 1900 Mr. Godfrey continued to serve as Director in charge of the financial department and took part in the inauguration and developments of the manufacture of commercial motor vehicles. He retired in 1910. He was elected an Associate of the Institution in 1879, and became a Member in 1880. E. H.

FRANCIS GEORGE HART was born at Canes in the parish of North Weald Bassett, Essex, on the 5th February, 1858, and died at Epping on the 21st November, 1921. He was educated mainly at Felsted Grammar School. After leaving school he helped his father on the farm for a time, but, this work not being congenial, he studied science and electricity at Hammond's Electrical School at Red Lion-square, Holborn. He afterwards joined Messrs. Phillips and Harrison, and later became connected with Messrs. Peto and Radford, of which firm he was the secretary for many years until it was amalgamated with Messrs. Pritchett and Gold and the Electrical Power Storage Company a short time before he died. He was a very keen Freemason and belonged to several lodges. He was elected a Member of the Institution in 1895. H. W. H.

EDWARD HOPKINSON, D.Sc., M.P., was the fourth son of Alderman John Hopkinson—one-time Mayor of Manchester and himself a distinguished mechanical engineer. He was born on the 28th May, 1859, and died on the 15th January, 1922. He was a member of a brilliantly gifted family—an elder brother was the late Dr. John Hopkinson, a Senior Wrangler and greatly distinguished as an electrical engineer, and another brother is Sir Alfred Hopkinson, the late Vice-Chancellor of Manchester University. Dr. Edward Hopkinson was educated at Owens College, Manchester, where he was Dalton Mathematical Exhibitioner. In 1877 he gained an Exhibition in mathematics to Emmanuel College, Cambridge, where later he secured a Foundation Scholarship in mathematics. He graduated as Tenth Wrangler in the Mathematical Tripos of 1881, and was elected a Fellow of his College in 1883. In 1881 he took the degree of Doctor of Science in the University of London in the branch of electricity and magnetism treated mathematically.

After leaving Cambridge Dr. Hopkinson became personal scientific assistant to Sir William Siemens, and in this capacity was engaged upon the design and construction of the first electric tramway in the United Kingdom—from Portrush to Bushmills in the North of Ireland. He read a paper on this undertaking, for which he was awarded a silver medal by the Society of Arts. In 1883, after the death of Sir William Siemens, he carried out on his own responsibility the design and construction of the Bessbrook and Newry Electric Tramway. This line was opened for traffic in 1885 and was supplied with power from a hydro-electric station; the electrical machinery was manufactured by Messrs. Mather and Platt of Manchester. Dr. Hopkinson read a paper on the construction and operation of this pioneer electric tramway before the Institution of Civil Engineers and was awarded a Telford Gold Medal and a Telford Premium. In 1884 he joined the firm of Mather and Platt and took charge of their electrical engineering department, where his great electrical knowledge found ample scope. He was made a partner in 1887, a managing director in 1892, and, when the company was enlarged in 1899 by the merging into it of the business of Messrs. Dowson, Taylor and Co., he was appointed Vice-chairman. He remained a member of the Board until his death. As a pioneer in the application of electricity to traction he worked out and was responsible for the whole of the designs for the first London tube, the City and South London Railway, which was also the first electrical tube line in the world. Here the innovation was made of building the motor armatures directly on the axles of separate locomotives without the intervention of gearing. This railway was opened in 1890 by the Prince of Wales, afterwards King Edward VII. In 1893 Dr. Hopkinson read a paper describing the design and equipment of this railway before the Institution of Civil Engineers, for which he was awarded a George Stephenson Medal and a Telford Premium. The Douglas to Laxey Tramway and the Snaefell Mountain Railway, both in the Isle of Man, were constructed somewhat later. Their electrical equipment was designed by Dr. Hopkinson and the work was carried out by Messrs. Mather and Platt under his direction, and there followed in a similar way the electric tramway from Blackpool to Fleetwood.

In 1891 Dr. Hopkinson was one of the founders of the Chloride Electrical Storage Co., Ltd., of which in 1892 he became joint managing director, and in 1896 vice-chairman, and he remained a director until his death. He was associated with his eldest brother, the late Dr. John Hopkinson, in the design and development of the "Edison-Hopkinson" dynamo and the "Manchester" dynamo, and he was joint author with his brother of a brochure on "Dynamo-Electric Machinery" read before the Royal Society in 1886.

Dr. Hopkinson was prominently identified with various engineering Institutions and Associations. He was elected a Member of this Institution in 1883, was a Member of Council 1892–94 and 1907–10. In 1900–1 he was the first Chairman of the Manchester Local Section and from 1905 to 1908 was a member of the

Local Committee. He also served on the Council of the Institution of Civil Engineers. He was elected President of the Institution of Mechanical Engineers in 1919, and had also been President of the Manchester Association of Engineers. He was a Vice-President of the Manchester Steam Users' Association, and one of the founders of the Engineers' Club.

Dr. Hopkinson's scientific knowledge and wide experience were applied to good purpose in many public capacities outside engineering subjects. He was appointed by the Government in 1916, and for two years remained, a member of the Indian Industrial Commission, in connection with which he made an extended journey to India, which, unfortunately, taxed heavily a constitution that was already showing some signs of overstrain from a life of constant and most strenuous activity. He was also a member of the Industrial Fatigue Research Board of the Department of Scientific and Industrial Research. He was a member of the Court of Governors of Manchester University and Chairman of the Associates of Owens College, and took the keenest interest in everything concerned with his old University. His sympathies in regard to social and welfare work were very broad. He worked tirelessly for and supported generously the Salford Royal Hospital, of which he was Treasurer and Chairman of the Extension Committee. He also took a very great interest from its inception in the David Lewis Epileptic Colony, of which he was Chairman, and in the Manchester Mill Girls' Institute. It was only comparatively recently that Dr. Hopkinson, who had little love for the glamour of public life, yielded to the persuasion of his friends and stood as candidate for the Clayton Division in Manchester in the Parliamentary Election of November 1918, when he was elected by a large majority. Unfortunately, the strain of the election following the effects of the journey in India still further taxed his strength, and from that time his health began to fail and he was not able to take a very active part in parliamentary life.

In early life Dr. Hopkinson was a keen Alpine climber, and he was equally at home on English rocks. He married Minnie, daughter of the late John Campbell, of Rathfern, Co. Antrim; they had two children, a son and daughter, who, with Mrs. Hopkinson, survive him. His death is a great loss to the country as well as to those who were his personal friends. He was a man in whom devotion to duty was an inspiring principle, and he infused energy and enthusiasm into every task that he took in hand. Even when his physical health began to fail, his mental activity never flagged, and his zeal in advocating the causes, social and political, which he had at heart, seemed, if possible, to grow in intensity, and now that he has gone his bright eager personality will be greatly missed by a wide circle of sorrowing friends.

J. R.

GISBERT KAPP, Dr.Eng., was born at Mauer, near Vienna, in 1852, and died at Selly Park, Birmingham, on 10th August, 1922. His father was a native of Trieste, and Civil Governor of that town. His mother was Scotch. He received his education as an engineer at the Zurich Politechnic School under Professors Zeuner and Kohlrausch. The good grounding obtained in mechanical engineering was evidenced throughout his successful career. After some practical experience and a year's service in the Austrian Navy, he came to England in 1875 and spent the most of his life in this country. He took out his naturalization papers as soon as possible and always looked upon England as his home. At first he was employed by Messrs. Gwynne and Co. in the design of centrifugal pumps, and was responsible for some land-drainage schemes in Holland. This was followed by some time spent as the representative of Messrs. Hornsby in Russia, Italy, and on the north coast of Africa.

Dr. Kapp's connection with electrical engineering commenced in 1882, when he was appointed by Colonel Crompton to be engineer of the Chelmsford works, and this connection lasted until the spring of 1885. The Patent Office records show that these years were fruitful in inventions for improvement in both the mechanical and electrical construction of dynamos, and for measuring instruments, etc. These patents were taken out conjointly with Colonel Crompton, and included one for the compound winding of dynamos.

In 1885 he commenced his practice as an independent electrical expert. He continued to make improvements in dynamos and his designs were manufactured by several firms in this country. His first paper on the subject, "Modern Dynamos and Their Engines," was read that year before the Institution of Civil Engineers and was awarded the Telford Medal and Premium. This paper is of historic interest and clearly shows the progress which had been made at that date in dynamo design, and the great need there was for improvement in many of the machines then on the market. The discussion indicates the general want of knowledge at that time as to the design of the magnetic circuit. Dr. Kapp's methods of calculation were simple and clear and, as a result, his paper helped many engineers to improve the machines for which they were responsible. In 1886 he read a paper before the Institution of Electrical Engineers on "The Predetermination of the Characteristics of Dynamos" which was another step in the same direction. In the same year the first edition of his book on "Electric Transmission of Energy" was published. Dr. Kapp wrote for the ordinary engineer, and avoided higher mathematics as much as possible. He did much to introduce the graphical treatment of electrical problems. His formulæ were always based on practical tests, and the information he obtained in this way was freely communicated to his contemporaries. This was done at a time when secrecy in such matters was too often the rule, and hence the exceptional value of his publications. In 1889 he read a paper on "Alternators" before the Institution of Civil Engineers, which is also historic and received the Telford Medal and Premium.

In 1889 he introduced the multipolar type of direct-current dynamo, the first machines being installed in the St Pancras electricity works. These dynamos had cast-iron field magnets, and worked successfully. They were the first examples of the now universally adopted type. In the same year the Amberley-road station of the Metropolitan Electric Supply Co. was equipped with alternators designed by him. These machines had

iron armature cores, whereas most of the alternators at that date were constructed without any iron in the revolving armatures. In 1891 he designed the first Corporation electricity works at Bristol acting as joint Consulting Engineer to the Corporation with the late Sir William Preece. He was then practising as consulting engineer in Westminster, and he designed several power distribution schemes for use abroad. His chief interest still lay in the perfection of electrical machinery and his patents are remarkable for their practical nature. Amongst these were several for the improvement in the mechanical design of dynamos and transformers, also a system of two-rate metering of electricity to enable the current supplied during the daytime to be charged at a lower rate than that supplied during the peak lighting hours. He also invented the system of negative boosting for the return feeders of electric tramways, which was widely adopted.

From 1894 to 1905 Dr. Kapp acted as Secretary of the Verband Deutscher Elektrotechniker in Berlin. At the same time he was Editor of the *Elektrotechnische Zeitschrift*. The object of the Society was standardization, and Dr. Kapp's thorough technical knowledge aided greatly in the work. His power of organization and tact were even more essential in reconciling many conflicting interests. As a result of his efforts a series of Standard Specifications were issued by the Society, and have been more or less adopted in other countries. Another series of regulations for electrical work, wiring rules, etc., were also prepared at this time. While living in Berlin, Dr. Kapp lectured to the post-graduate students of the Technical High School at Charlottenburg on electrical design, and the Universities of Dresden and Karlsruhe both conferred on him their honorary degree of Doctor of Engineering. With all these responsibilities Dr. Kapp still found time to act as independent electrical adviser, and his services were in demand. Besides acting as arbitrator, he designed schemes for power supply, lighting and traction. Amongst the towns he advised were Moscow, Trieste, Leipsig and Trondjiem. He had also to do with power schemes in Switzerland and Italy.

In 1904 he was offered the new professorship of electrical engineering by the Birmingham University, and he received a hearty welcome back to England on taking up his duties the next year. He devoted himself almost entirely to his students, giving the lectures on electrical engineering personally. His wide knowledge both of English and Continental practice added great interest to these lectures and he had a wonderful power of stating concisely the essentials of any particular equipment or process. The growth of the Department was seriously handicapped by the War, as the University buildings were converted into a hospital and most of the students into soldiers. Dr. Kapp always encouraged independent thought, and his students took their lead from him. It was during this time that he perfected the vibrating phase-advancer for improving the power factor of alternating-current motors. The students obtained valuable experience in the experimental work on this type of apparatus which has been widely adopted in this country. He retired from the University in 1919. Soon after his return to England he began to have trouble with his eyes and for the last few years was seldom free from great discomfort. He did not allow this to interfere with his activities. Elected an Associate in 1883 and a member in 1887, his connection with the Institution of Electrical Engineers extended over nearly 40 years and he served ten of these on the Council. He contributed 11 papers to the Proceedings and regularly took part in the discussions on papers read by others. While in Birmingham he took a most active part in the meetings of the Local Centre and was Chairman in 1907–8. Elected Vice-President in 1907, he was made President of the Institution in 1909 and his Address was a wonderful résumé of progress.

His record as a pioneer of the electrical industry is an exceedingly full one. When working at his usual high pressure he spared neither himself nor those associated with him. He made many friends and was a delightful host. His recreations were sailing, golf and music. He married in 1884 Therese Mary Krall, and had two sons, both of whom have followed in their father's profession.

R. W. W.

RANDAL BERESFORD SLACKE was born in 1876 and was the son of the late Sir Owen R. Slacke, C.B. After receiving his early education at Newton Abbott he went to Marlborough College, from which institution he proceeded to the City and Guilds Central Technical College, and studied there during the years 1894–7. In the latter year he was articled to Mr. E. W. Cowan and was engaged during the first year of his course as pupil in the Altrincham supply station of the Edison Swan Company. He spent the year 1898–99 partly as pupil in the Salford works of Cowans, Ltd., and partly in St. Petersburg, where he went in charge of the erection of a large high-tension switchboard, a work which occupied seven months. During 1899–1900 Mr. Slacke was a pupil in the shops of Messrs. Browett, Lindley and Co., Ltd., and was engaged on engine work, erecting, testing, etc. In 1901 he entered the service of the Blackburn Corporation Tramways Department and was placed in charge of the erection of about 10 miles of overhead construction as well as of the maintenance and running of the cars. During the years 1901–4 he was a partner in the firm of Messrs. G. H. Woods, Slacke and Co. of Blackburn, and in that capacity carried out many large contracts for electric power, lighting, etc. From 1905 to 1910 he was associated with the Key Engineering Company, taking an active part in its management and affairs, becoming a director and being placed in charge of the Manchester office. While so engaged he became interested in the development of large gas engines, and in 1907 and again in 1908 he assisted in conducting parties of British engineers on a tour of inspection of some of the Continental works in which such engines were to be seen in successful operation. In 1909 he took some of the directors of Messrs. Galloways, Ltd., for a similar trip, which resulted in that firm taking up the manufacture of large gas engines in this country. It also led to his being invited to join the staff of Messrs. Galloways, Ltd., which he did in 1910, becoming London manager to the firm, in consequence of which he resigned his managership of the Key Engineering

Company, although retaining his seat on its Board. Later in the same year he made a tour of inspection in South America on behalf of Messrs. Galloways. Upon the outbreak of the war he enrolled as a Derby recruit and, as an old volunteer, did some very useful work in training men for active service. At the same time he was also engaged on anti-aircraft searchlights and later gave valuable voluntary assistance to the engineering staff of the Metropolitan Munitions Committee. In 1917 he resigned his appointment with Messrs. Galloways to accept a commission in the Royal Engineers, and his promotion was rapid. In November 1917 he was lent to the Admiralty for duty as Deputy Assistant Director and Assistant Director of Materials and Priority. On the 1st March, 1919, shortly after his demobilization, he joined the staff of *The Engineer*, and in July of the same year was appointed manager of that journal, a post which he held at the time of his death. He was a man of charming personality who was admired and liked by all with whom he came into contact for his uprightness and straight dealing. Early in life he was an expert Rugby footballer, and for several years played in the Manchester team. He was a good all-round sportsman, an expert with yachts, and a keen rider to hounds. He died on 28th February, 1922, as a result of an accident in the hunting field. He was elected an Associate Member of the Institution in 1902, and a Member in 1907. H. C.

HERMANN SLOOG was born in Amsterdam in 1884, and died in November, 1921. He was educated at the College Rollin, of Paris University, and in 1903 gained admission to the École Centrale des Arts et Manufactures in Paris. In 1906 he left the school with the diploma of engineer. He was then for some time engineer to the Société Anonyme de la Lampe M.S. in Paris, which specialized in the manufacture of metal filament lamps. Coming to London, he was engineer to the Phœnix Telephone Co., Ltd., eventually becoming Chief Engineer to the Company. Since 1913 he acted as consulting engineer in Great Britain to a number of French firms. Strongly imbued with altruistic feelings, he acted, from the very formation of the small but influential group of former pupils of the École Centrale established in this country, as Honorary Secretary to the group, and proved invaluable to all "camarades" who had professional or business relations with Great Britain. From the group sprang up a wider organization—the group of former students of French Universities and "Grandes Écoles" of which he was also Honorary Secretary. Gradually the idea evolved and gave rise to the now so well-known "Franco-British Inter-University Group." At the same time he became the moving spirit of the British Section of the Société des Ingenieurs Civils de France, which brings together the numerous members of the parent Society who reside in Great Britain and the British Empire. Through his untiring efforts as Honorary Secretary great success was achieved by the visits paid by the British Section to the devastated mining districts in France in June 1920, and to the metallurgical works of Eastern France in June 1921. His great desire was always to assist in improving the relations between the professional and intellectual circles of the two nations, and it was for the furtherance of this aim that he accepted also the heavy work entailed by the Honorary Secretaryship of the Board of Control of the British Bureau of the Office National of French Universities. He paid particular attention to the exchange of engineering students, and large numbers of those attending the summer courses at Grenoble University remember his untiring and helpful efforts on their behalf. A few years before his death he was elected to the Council of the Society of Engineers. He was greatly liked and held in high esteem by all who had the privilege of coming in touch with this loyal, obliging, helpful and disinterested friend, this admirable organizer and indefatigable worker. He was elected an Associate Member of the Institution in 1913, and a Member in 1921. T. J. G.

COMMODORE EDOUARD SUENSON was born in 1842 and died at Copenhagen on the 21st September, 1921. Belonging to an old family of sailors—his father being Vice-Admiral Suenson who won the engagement off Heligoland in 1864—it was natural that he should enter the Danish Navy, where he attained the rank of Lieutenant. He made his first acquaintance with the Far East when, in 1865–68, he served in the French Navy and was wounded in Korea. In 1870 he joined the Great Northern China and Japan Extension Telegraph Company—later amalgamated with the Great Northern Telegraph Company, Ltd.—for the purpose of proceeding to the Far East, where the first cable was landed on the coast of China under his personal supervision and where he organized the pioneer work of the company. After his return to Denmark he became, in 1874, general manager and in 1890 managing director of the company, a position which he held until 1908. In 1898 he was elected chairman of the Board of Directors, and in this position he remained until the end of 1915 when illness compelled him to resign, the Board conferring upon him the dignity of its honorary chairman. Nature had endowed Commodore Suenson with exceptional diplomatic gifts and with a distinguished and prepossessing personality. It was due to those qualities more than to anything else that the Danish concern made its way in spite of many adversities, extended its sphere of action and gradually won its present standing. In his many important negotiations with Governments and telegraph companies, as well as at the International Telegraph Conferences, his intellect and quickness of thought stood him in good stead, and at the same time his rectitude and his far-sighted views won him the confidence and esteem of his contemporaries. He enjoyed a high authority in the telegraph world and was frequently consulted by telegraph officials in different countries. In former years he often visited London, where he had many friends in the General Post Office and in the telegraph companies. The Commodore's name is indelibly inscribed in the annals of the Great Northern Telegraph Company. In a big nation a personality such as his would make itself prominent in the history of his time. He belonged to a small nation and, furthermore, the aim of his unselfish mind was not personal distinction. The object

of his life was the honour and success of his company and, through its progress and activity, to benefit his country. His lifelong, strenuous work to this end did not allow him to rest and only ceased when, in spite of his strong constitution, he had positively worn himself out. He was elected a Foreign Member of the Institution in 1875, and a Member in 1911. P. M.

FRANK FORREST TALBOT was born in London on the 6th August, 1844, and died in Rosario, Argentina, on the 15th April, 1922, after a short illness. He went to the Argentine in 1864, and was engaged in the construction of the telegraph and electric signalling for the Northern Railway of Buenos Aires. In 1868 he undertook the construction of the telegraph system and the electric lighting of the Central Argentine Railway, with which the Northern Railway was afterwards amalgamated. He remained with the company until 1905, when he retired on pension, superintendent of the Central Argentine Railway telegraph and electric light systems. He was elected an Associate of the Institution in 1874, and a Member in 1878.

FREDERICK WILLIAM TOPPING was born in London in 1851. As a young man he joined the Eastern Telegraph Cable Company at Porthcurnow, Cornwall, where he remained six months. He was then appointed a member of the expedition staff to India under Lord Kelvin (then Sir William Thomson). After three years spent at this work both in Madras and Singapore he returned to England. It was his intention to return to India, but on his arrival he was offered the position of clerk in charge at the Direct United States Cable Co.'s station at Ballinskellings, where Messrs. Siemens Brothers were bringing the cable into the bay, which is the most southerly point in Ireland. A few years later, before he was 30 years of age, he was offered the position of superintendent of that station; this he accepted and held for nearly 40 years, until he retired with a pension in 1910 and went to live at Paignton, Devonshire. His death occurred at Penzance on the 24th February, 1922. The numerous letters of sympathy and wreaths from both public bodies and private friends showed the high esteem in which he was held by all who knew him. He was elected an Associate of the Institution in 1877, and a Member in 1903. J. T.

ALBERT HARRY UNWIN was born in Kent on the 23rd January, 1862, being descended from a very old English family. He was educated at Dulwich and later served an apprenticeship with Messrs. John Penns, Ltd. (afterwards the Thames Iron Works). On leaving that firm, realizing that electricity would be used for lighting in the future, he apprenticed himself to the Brush Electric Company, Loughborough, and it was during his subsequent employment by this Company that he was sent to the Argentine in 1888, where amongst his many enterprises may be mentioned the construction and running of the first electric works in La Plata, Montevideo, Tucuman and the Catalina Mole in Buenos Aires and Rosario, which have earned him a prominent place among the best-known electrical experts in Argentina. At Rosario his latest achievement was the building of a new power station which was the only one of its kind in South America having a horse-power of 40 000. He was always amongst the most patriotic of his countrymen and during the war showed his patriotism in a most practical manner on every occasion. He occupied the presidency of the Rosario British Patriotic Society, was in the British secret service and was the founder of the Chamber of Commerce, for which he did most valuable work. He visited England three times during the war and in 1919 retired to this country and was living at Totland Bay, Isle of Wight, at the time of his death, which took place suddenly on the 1st December, 1921, and which no doubt was caused partly by the strain of extra duties enforced upon himself by his extreme patriotism. He was elected a Member of the Institution in 1898. V. E. S.

GEORGE GRAY WARD was born at Great Hadham, Hertfordshire, on the 30th December, 1844. He developed a taste for telegraphy at an early age and while still at school received a prize for knowledge of the art. After completing his education he entered the service of the Electric Telegraph Company and soon attracted attention because of his aptness and industry. His promotion was rapid. In 1865 he entered the Egyptian Government Telegraph Service and for some three years was stationed at Alexandria. He was one of the few Europeans to stick to his post during the cholera epidemic of 1865, and his valuable services were specially recognized by the Viceroy, Ismael Pasha. He resigned from the Egyptian service in 1869, joined the first French Atlantic Cable Company, and was assigned to accompany the s.s. "Great Eastern" as a member of the electrical staff during the laying of that company's cable. Later, as superintendent of the Direct United States Cable Company, he organized that company's system in the United States. There he made his first great impression upon the industry, to the furtherance of which he was to devote his entire life. Through his efforts the transmission of messages between New York and London was so greatly accelerated that arbitrage transactions between the Stock Exchanges of the two cities were enabled to take place, a feat which had not been possible before. He also accelerated the transmission of news dispatches between the old world and the new, and it was he who introduced the system of registered addresses which since has been adopted throughout the world and has saved the cabling public considerable expense. In 1884 he became general manager of the Commercial Cable Company and in 1890 was elected vice-president, positions which he held until his death. In this new field he was even more successful than he had been in earlier positions. His sound judgment and business ability, together with his power to maintain discipline, while holding the respect and affection of his subordinates, were assets of the utmost value. In 1906 after the laying of the Commercial Pacific Cable he was decorated by the Emperor of Japan with the Order of Commander of the Rising Sun. He died on the 15th June, 1922. One outstanding feature of his lovable nature was the absolute simplicity of his character. He was a man who, by reason of his ability and personal charm of manner, was *persona grata* everywhere and in all classes of society. Everything he touched in the business

world was crowned with success, and a feeling grew up among his colleagues that anything to which he put his hand might be counted an accomplished fact. Few men would have been proof against such an unchequered career, but we, who knew him so long and so intimately, knew that he retained to the end of his life the same untarnished simplicity. It is but right to say that the example of his noble life has left its impress on the company, and happy shall we, who are left, be in our endeavours if we can but carry on the tradition of his high ideals. He was elected an Associate Member of the Institution in 1874, and a Member in 1877, and served as Local Honorary Secretary and Treasurer for the United States of America from 1876 to 1922. H. F. R.

JOSEPH WILKINSON, born in 1868, was the eldest son of Mr. John Wilkinson, of Middleton-in-Teesdale. From 1884 to 1886 he was apprenticed to Messrs. Cox-Walker and Co., Darlington, and was also a student at the Darlington Technical School. He then joined the firm of Messrs. J. H. Holmes and Co., Newcastle-on-Tyne, and continued his studies at the Durham College of Science. Amongst other work, he carried out a great deal of ship lighting. In 1888 and 1889 he was employed by the Transatlantic Company of Cadiz and Barcelona as electrical engineer on the "Alfonso XII" and "Alfonso XIII." In 1890 he joined the Chilian Navy and supervised the electrical equipment of the torpedo boat destroyer "Almirante Condell," subsequently sailing in that vessel to Valparaiso. On his return to England in 1891 he became an assistant engineer in Messrs. Siemens Brothers and Co., and shortly afterwards went to Tasmania in connection with the installation of the electrical tramway system at Hobart. He then returned to England and acted as resident engineer for Messrs. Siemens Brothers in connection with the equipment of the Blackburn tramways. He was transferred from Blackburn to Hull in 1899 in connection with the equipment of the Hull tramway system, and in 1903 was appointed tramways electrical engineer in that city, a position which he held for about 16 years, eventually retiring to practise as a consulting engineer. He died suddenly from heart trouble on 7th July, 1921. He was elected a Member of the Institution in 1903.

ROGER HURST WILLIS was born in 1872 and died at Manchester on the 17th September, 1921. He was the eldest son of the late Reverend Thomas Willis of Manchester. Educated at Manchester Grammar School and Manchester Technical School, he showed, early in his career, a marked leaning towards engineering and, on leaving school, entered the works of Messrs. Mather and Platt as an apprentice. Subsequently he held the position of outside manager for some 10 years. While with this firm he was associated with the late Dr. Edward Hopkinson on many of the earliest electrical schemes, among which were the Snaefell and Laxey Railway and the Blackpool and Fleetwood Tramways, on the construction and equipment of both of which he was resident engineer. In 1905 he accepted the position of general manager to the British Electric Plant Company, at Alloa, a position which he retained until 1914, when he returned to Manchester, where he specialized in engineering requirements for textile mills and collieries. In 1919 he joined the firm of Messrs. Crompton and Co., Limited, as engineer and manager of their Manchester office. He was connected with the Association of Mining Electrical Engineers from its inception, representing the East of Scotland Branch (of which he was Honorary Secretary) on the General Council in 1910. Transferring later to the West of Scotland Branch, he again became Member of Council and was afterwards elected to the Advisory Committee (of three) which had virtually the executive control of the Association's interests. In 1914 he became Honorary Secretary and Treasurer of the Lancashire, Cheshire and North Staffordshire Branch of the Association, of which he became President-elect in 1921. It was chiefly owing to his untiring efforts that the Association began to publish its Transactions in a technical journal of its own. He was elected an Associate Member of the Institution of Electrical Engineers in 1900, and a Member in 1908. R. W. W.

RICHARD ERNEST WINKFIELD was born on the 15th December, 1867. He received his technical education at the Great Western Railway Company's works, Swindon, 1886–89, and from 1889 to 1892 was employed as a draughtsman and assistant engineer to the Great Western Railway Company at Swindon and Paddington. During the following six years he occupied the position of assistant engineer to the Metropolitan Electric Supply Company, and in 1898 he joined the British Thomson-Houston Company's Construction Department and was engaged on several important contracts in connection with the electrification of the Central London and the Great Northern and City Railways. On the completion of these contracts he accepted the post of chief assistant engineer to the Calcutta Electric Supply Corporation, Ltd., and proceeded to India in 1904. He was promoted to chief engineer in 1909. Four years later he took over full charge of the Corporation's affairs in India, with the title of agent and chief engineer. During his tenure of office in India the whole system of generation and supply of electricity to the City of Calcutta and suburbs was remodelled. The several small direct-current generating stations were superseded by one large extra-high-tension power house, connected by means of high-tension cables with the necessary converting substations built in the best positions obtainable in the area for efficient distribution. He resigned his position in India at the beginning of 1920, and on his return to England was appointed by the directors of the Calcutta Electric Supply Corporation general adviser to the Corporation, which position he held until his death. He was an honorary magistrate in Calcutta and his technical knowledge was invaluable in deciding complicated motor-car cases. He was also Chairman of the Electricity Sub-Committee of the Bengal Chamber of Commerce. His spare time was devoted to floriculture and scientific research. He was very artistic and musical, and his unfailing courtesy and charming personality will ever remain in the memory of his friends. He died on the 26th September, 1921. He was elected a Member of the Institution in 1910. In 1913–14 he was chairman of the Calcutta Local Section. J. T. M.

THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 29. Dec. 1921. INSTITUTION NOTES. [ISSUED WITH No. 306 OF THE JOURNAL]

Arrangements for January 1922.

ORDINARY MEETINGS OF THE INSTITUTION.

(Thursdays.)

[To be held at The Institution, Savoy Place, Victoria Embankment, W.C. 2, at 6 p.m. (light refreshments 5.30 p.m.).]

Date. 1922.	*Author and Title of Paper.*
5 Jan.	Dr. S. P. Smith: "Single- and Three-phase Commutator Motors with Shunt and Series Characteristics" (Lecture with experiments, to be followed by a discussion).
12 Jan.	Exhibition of cinematograph films: (*a*) "Investigations and Tests on High-tension Switchgear," by Mr. P. Torchio, with explanatory notes by Dr. C. C. Garrard; (*b*) "Telephone Inventors of To-day," exhibited by Mr. F. Gill; and, if time permits, (*c*) "Electricity in the Home," exhibited by Mr. F. Gill.
19 Jan.	Discussion on "The Utilization of Waste Heat from Electrical Generating Stations." (Joint Meeting with the Institution of Heating and Ventilating Engineers.)

MEETING OF THE WIRELESS SECTION.

(Wednesday.)

[To be held at The Institution, Savoy Place, Victoria Embankment, W.C. 2, at 6 p.m. (light refreshments 5.30 p.m.).]

4 Jan.	Lieut.-Col. A. G. T. Cusins, R.C. of S.: "High-speed Wireless Telegraphy."

INFORMAL MEETINGS.

(Mondays.)

[To be held at The Institution, Savoy Place, Victoria Embankment, W.C. 2, at 7 p.m.]

9 Jan.	J. W. Beauchamp: "Co-operative Advertising in Relation to the Electrical Industry."
23 Jan.	R. J. Mitchell: "Electrical Vehicles, Present and Future."

MEETINGS OF TERRITORIAL CENTRES AND SUB-CENTRES.

Date. 1922.	*Place of Meeting.*	*Author and Title of Paper.*
3 Jan.	Loughborough.	Address by Mr. R. A. Chattock.
9 Jan.	Dundee	C. Lamb: "Electrical Distribution."
9 Jan.	Newcastle	L. H. A. Carr: "Induction-type Synchronous Motors."
10 Jan.	Edinburgh	L. H. A. Carr: "Induction-type Synchronous Motors."
10 Jan.	Manchester	E. S. Byng: "Telephone Line Work in the United States."
11 Jan.	Birmingham	L. J. Steele & H. Martin: "The Cyc-Arc Process of Automatic Electric Welding."
11 Jan.	Middlesbrough	L. H. A. Carr: "Induction-type Synchronous Motors."
16 Jan.	Bristol	Lecture by Mr. J. W. Beauchamp.
16 Jan.	Liverpool	Exhibition of the cinematograph films shown in London on the 12th January.
17 Jan.	Leeds	Dr. S. P. Smith: "Single- and Three-phase Commutator Motors with Shunt and Series Characteristics" (Lecture with experiments, to be followed by a discussion).
23 Jan.	Newcastle	(To be announced later.)
24 Jan.	Loughborough	R. B. Leach: "Loughborough Electricity Undertaking and Extensions in Hand."
24 Jan.	Manchester	L. J. Steele & H. Martin: "The Cyc-Arc Process of Automatic Electric Welding."
26 Jan.	Middlesbrough	C. H. Davidson: "Methods of Conversion of Alternating Current to Direct Current for Traction Purposes."

LONDON STUDENTS' SECTION.

MEETING.

[To be held at The Institution, Savoy Place, Victoria Embankment, W.C. 2, at 7 p.m.]

Date. 1922.	*Author and Title of Paper.*
20 Jan.	L. T. Hinton "Some Applications of the Thermionic Valve to Telephony."

VISITS.

Date. 1922.	*Works to be Visited.*
13 Jan.	Cosmos Lamp Works, Brimsdown.
28 Jan.	Messrs. D. Napier & Sons, Ltd., Acton.

The above visits are open *only* to Students of the Institution. Students wishing to attend must notify Mr. H. J. Howard, 115, Queen's Road, Wimbledon, S.W. 19, at least 10 days before the visit (21 days in the case of the visit on the 28th January). When the number of the party is limited, the Committee reserve the right to decide, by ballot or otherwise, which Students may attend.

Annual Dinner.

The next Annual Dinner of the Institution will be held on Tuesday, 21st February, 1922, at the Hotel Cecil.

Summer Meeting.

Arrangements are being made for a Summer Meeting to be held at Glasgow and the Western Highlands in May or June next. The programme will be similar to the one arranged for the meeting which was to have been held in 1921.

Honorary Member.

At the Ordinary Meeting of the Institution on the 17th November, 1921, the President announced that the Council had elected the Right Hon. Lord Southborough, P.C., G.C.B., G.C.M.G., G.C.V.O., K.C.S.I., an Honorary Member of the Institution.

Lord Southborough was present at the meeting when his election was announced, and thanked the members for the honour conferred upon him.

List of Members.

A revised edition of the List of Members is in preparation and will be ready in February. Only a limited number of copies will be printed, and any member desiring to receive one is requested to make early application to the Secretary.

Library.

At the Ordinary Meeting on the 3rd November, 1921, the President announced that the Council have decided to keep the Library open in future on two evenings each week until 9.30 p.m., or alternatively one evening a week and Saturday afternoon until 5 p.m. In order to ascertain which days are most favoured by members, the Library will for a few weeks be kept open every weekday evening and every Saturday afternoon.

Bibliographies of Special Subjects.

Members who have compiled bibliographies or reference lists of special subjects are invited to send particulars to the Secretary.

It is proposed to keep in the Institution Library a note of all such bibliographies and lists, with a view to making it possible for members desiring information on particular subjects to be put into communication with those in a position to supply it.

In those cases where it is possible to present to the Institution the actual bibliography or list, or a copy of it, the Council would greatly appreciate the gift, as this would considerably extend the utility of the arrangement.

Information as to bibliographies available will be published from time to time in the *Journal*.

London Students' Section.

Mr. C. C. Paterson, O.B.E., has been appointed to be the Member of Council to act as Consultative Member of the London Students' Committee for the session 1921-22.

Premiums for Students' Papers.

The Council have decided that in future a maximum of six Students' Premiums of £10 may be awarded each year if the papers are of sufficient merit, and that in considering the awards the papers be classified as follows :—

(1) Design and Manufacture of Electrical Plant.
(2) Generation and Distribution of Electric Power.
(3) Utilization of Electric Power (Traction, Power and Lighting, and Electrochemical).
(4) Telegraphy and Telephony.
(5) Wireless.
(6) Unclassified.

In the event of a premium not being awarded in any section, two premiums may be given in another section provided that the papers are specially meritorious.

Associate Membership Examination.

The following are lists of the successful candidates at the examination held in the United Kingdom in October last :—

Whole Examination.

P. C. Bhandari (London).
F. J. Bown (Newcastle-on-Tyne).
B. A. Cronin (Cardiff).
E. R. Fry (London).
G. K. Johnson (Prescot).
E. E. Jolly (Southampton).
W. G. Stokes (Manchester).
H. S. Webster (Cardiff).

Part II only.

D. K. Hall (London).
P. W. Tucker (London).

(The results relating to candidates who sat for the Examination abroad will be published later.)

Officers of the Royal Engineers.

Whole Examination.

Lieut. G. D. S. Adami.
2nd Lieut. H. F. T. Aldous.
2nd Lieut. N. Boddington.
2nd Lieut. G. K. Cassels.
2nd Lieut. P. J. Cator.
2nd Lieut. D. R. Crone.
2nd Lieut. R. S. Dalby.
2nd Lieut. E. V. Daldy.
2nd Lieut. J. A. Davies.
2nd Lieut. R. W. J. Dunn.
2nd Lieut. A. J. Edney.
2nd Lieut. J. S. Forbes.
2nd Lieut. F. H. R. French.
2nd Lieut. R. R. Gillespie.
2nd Lieut. C. G. B. Greaves.
2nd Lieut. G. W. Harris.
2nd Lieut. G. E. H. Hawkes.

OFF CLRS OF THE ROYAL ENGINEERS—*contd.*

Whole Examination—contd.

2nd Lieut. F. J. R. Heath.	2nd Lieut. H. F. Seymour.
2nd Lieut. J. M. Herrold.	2nd Lieut. S. St. D. Skinner.
2nd Lieut. C. E. Howard-Vyse.	2nd Lieut. R. Swaine.
2nd Lieut. S. Lamplugh.	2nd Lieut. D. C. T. Swan.
2nd Lieut. C. E. Montagu.	Lieut. K. H. Tuson.
2nd Lieut. A. Murray.	2nd Lieut. W. J. Vezey.
2nd Lieut. H. E. M. Newman.	2nd Lieut. Ll. Wansbrough-Jones.
2nd Lieut. J. D. Newman.	2nd Lieut. P. G. Wavish.
2nd Lieut. W. H. Ray.	2nd Lieut. H. M. Whitcombe.
2nd Lieut. E. E. N. Sandeman.	2nd Lieut. W. S. Wise.

Part II only.

2nd Lieut. J. B. P. Angwin.	2nd Lieut. E. J. Palairet.
2nd Lieut. A. Bennetts.	2nd Lieut. H. E. G. St. George.
2nd Lieut. C. E. A. Graham.	2nd Lieut. S. R. C. Shaw.
2nd Lieut. L. F. R. Kenyon.	2nd Lieut. G. M. Stewart.
2nd Lieut. B. H. S. Lloyd.	2nd Lieut. J. Stuart.
2nd Lieut. A. J. Macdonald.	2nd Lieut. R. C. Walker.
	2nd Lieut. A. G. Wyatt.

Part I only.

2nd Lieut. J. L. H. Chase.	2nd Lieut. E. H. T. Gayer.
2nd Lieut. A. R. Churchill.	2nd Lieut. H. E. Pike.
	2nd Lieut. J. R. Simpson.

Informal Meetings.

The following Informal Meetings have been held :—

23RD INFORMAL MEETING (7TH NOVEMBER, 1921).

Chairman : Mr. J. S. Highfield.

Subject of Discussion : "How Best to Speed up Electrical Progress" (introduced by Mr. J. S. Highfield).

Speakers : Messrs A. F. Harmer, P. S. Fox, E. T. Williams, T. Rich, M. Farrer, W. E. Warrilow, G. L. Addenbrooke, W. L. Wreford, A. B. Eason, W. G. Johnson, W. E. Rogers, W. Dargavel, J. R. Bedford, A. D. Chamen, W. C. Kennett, and F. Pooley.

24TH INFORMAL MEETING (21ST NOVEMBER, 1921).

Chairman : Mr. J. F. Avila.

Subject of Discussion : "Hydro-Electric Power" (introduced by Mr. A. J. Hainsworth).

Speakers : Messrs. J. Coxon, R. D. Gifford, D.Sc., W. E. Rogers, W. M. B. Macdonald, R. S. Allen, D. F. Campbell, P. M. Baker, P. S. Fox, E. F. Hetherington, A. G. Hilling, L. M. Jockel, A. N. Aikman, R. L. Narayanan, E. L. Webb, M. R. Gardner, G. E. Taylor, E. M. Pearson, J. R. Harding, G. J. D. Scott, and R. Grierson.

Electrical Research.

The Secretary of the Institution has received from the British Electrical and Allied Industries Research Association the following :

QUARTERLY PROGRESS REPORT BY THE DIRECTOR OF RESEARCH (SEPTEMBER 1921).

SECTION A : FIBROUS INSULATING MATERIALS.

Fabrics, untreated and treated.—Study of users' requirements has shown that these could be met, except in two special cases, by the provision of two classes of treated fabric. The Committee is now concentrating attention on the class requiring the highest grade material. This material has been purchased in the past principally on a basis of price, breakdown voltage and appearance. The Committee is developing better technical criteria.

Attention is being given to testing these materials under the conditions under which they are employed, but the results obtained are being studied with a view to reducing the data to fundamental constants.

Papers, untreated and treated.—The experimental examination of proposed methods of testing untreated papers has been completed and considerable improvements effected. These are being embodied in a specification prior to further study of the bearing of the results obtained on the selection of papers for particular purposes.

Fibres and boards.—These have been classified under three heads, viz. pressboard (including material known as press-spahn), varnish-paper boards and tubes, and vulcanized fibre. These are being made the subject of separate researches. The methods of testing the various qualities of pressboard have been developed experimentally, and a specification is now nearly completed. Corresponding work on the varnish-paper class is still in the experimental stage. Vulcanized fibre is still the subject of study, but it is expected that a comprehensive experimental examination of available materials will be made shortly.

SECTION B : COMPOSITE INSULATING MATERIALS.

The programme of experimental work has reached a stage which has enabled the Committee to complete a specification covering most of the mechanical and electrical properties of importance. A specification has been drafted embodying the results obtained, and a comprehensive report is in preparation on the whole of the work done. Test-results have already been furnished to manufacturers who supplied materials for the experimental work.

Inflammability, machining qualities and some other properties are still under investigation.

SECTION C : PORCELAIN.

A comprehensive research on insulation resistance, improvement of surface and electric strength is now in hand. The Post Office is co-operating and has furnished numerous samples of telephone insulators having surface deposits affecting the insulating properties. Samples are being obtained for resistance tests at high temperatures, and manufacturers have been

invited to submit samples of the principal grades of porcelain used in the electrical industry for examination.

Section D : Mica.

The classification of micas having been completed, the Committee is now able to study in detail the properties of the several classes in use. Much of this study will be on lines common to all insulating materials and will be carried out in co-operation with the new Section L. A Sub-Committee has been formed, however, to carry out further investigations into the mechanical properties of micas.

A report of the work of the Sub-Committees dealing with industrial applications, viz. mica for commutators and for condensers, is now in preparation. Experimental researches on abrasive hardness are not yet completed.

A Sub-Committee has been formed also to review the possibilities of research for the benefit of manufacturers and of users of micanite.

Section E : Insulating Oils.

Good progress is being made in the numerous researches referred to in the last report, but they are not yet ready for publication.

A comprehensive programme is in preparation for the study of resistivity in relation to moisture content and dielectric strength. Some new facts observed by experimenters require consideration before this programme is completed.

The Specification for insulating oils is still under consideration by the British Engineering Standards Association. Good progress has been made in dealing with improvements suggested by various interests.

Section F : Conductors.

The work on buried cables at the National Physical Laboratory and at Newcastle will be reviewed shortly by the Committee. Good progress has been made in tests on isotherms in the oil, moisture content, thermal resistivity, and dielectric losses. The work has been delayed by the necessity of carrying out on finished cable tests which it was hoped could have been made on component parts.

Reports are to hand on tests of overhead line conductors, except those to be carried out on long lengths.

Tests on the strength of wood poles for pole lines are well in hand. The poles and tackle have been erected and now await settlement of the ground.

Section G : Electric Control Apparatus.

Phenomena of switching and arcing.—A comprehensive programme of experimental research on oil switches has now been completed, and good progress has been made in developing methods of investigating pressure developed and many other factors entering into the rupturing capacity of oil circuit-breakers. An adaptable model switch is well in hand, as also are designs of especially sensitive recording apparatus of various kinds which will be required.

Mining switchgear.—The Home Office is continuing research at the experimental station at Eskmeals on the pressures developed in switchgear by gaseous explosions, and a start has been made at the N.P.L. on the examination of the pressures developed in closed chambers on rupturing an electric circuit in air.

Heavy-duty fusible cut-outs.—All available data on fusible cut-outs is being collected and brought under critical examination.

Consideration has been given to methods of testing, and some preliminary tests are being made prior to a thorough examination of existing models now to hand of ordinary-duty fusible cut-outs. The programme of work on heavy-duty fuses will be built up on the results obtained.

D.C. circuit breakers.—Extensive inquiries have shown that there is a considerable lack of both fundamental and empirical data on rupturing circuits in air. Service conditions have been classified, the available data on rupturing capacity has been studied, and the Committee is developing with great interest an experimental programme under the direction of representatives of manufacturers and users. It is hoped to commence experimental tests at once with the co-operation of the electrical engineers of the London County Council and the London & North-Western Railway.

Resistivity of joints and contacts.—A preliminary examination has been made of a number of joints of long standing in a heavily-loaded existing installation, and a comparison has been made with proposed standards. These results will be useful in developing a full programme which now awaits a report of extensive work already done at the N.P.L. and elsewhere.

Section H : Corrosion of Condensers.

Full consideration has been given to the work of the Corrosion Committee of the Institute of Metals, in which the Association participates. It is expected that a condensed report will be published shortly, explaining the results already obtained. Special attention will be given to bringing the manufacturers into touch with the investigators during the progress of the experimental work.

Section J : Turbine Researches.

Members are keeping in close touch with the experimental work being carried out at the College of Technology, Manchester, on nozzles, and it is hoped shortly to extend the scope of this work.

Attention is being given to questions of temperature distribution in steam turbines, and to extension of knowledge of the properties of steam.

Progress is being made with the research on blading. Materials are being tested by manufacturers under working conditions in co-operation with the N.P.L.

Section K : Synthetic Resins.

A Sub-Committee, working in co-operation with Section A, is investigating experimentally the properties of insulating materials of synthetic resins made up with a fibrous support.

A conference has been held with representatives of interested Government Departments through the good offices of the Department of Scientific and Industrial Research, and a good understanding has been arrived

at as to the requirements for different classes of service which might be filled by the use of materials with a synthetic resin base.

Inquiries have been started with a view to ensuring adequate supplies at all times.

Examination of moulded materials has been delayed pending the completion of a Specification by Section B, now nearly ready.

SECTION L: DIELECTRICS IN GENERAL.

This new Section is taking over all the work commenced by the Joint Committee on Dielectric Losses and Allied Phenomena, which has now been disbanded. It is bringing under review all the research work on insulation, with a view to furthering fundamental research and co-ordinating the work of other Committees.

Committees, 1921-1922.

Among the Committees appointed by the Council for 1921–22 are the following:

INFORMAL MEETINGS.

The President.

Mr. J. F. Avila.	Mr. A. F. Harmer.
Mr. J. R. Bedford.	Mr. E. F. Hetherington.
Mr. H. T. Body.	Mr. E. W. Moss.
Mr. A. B. Eason.	Mr. C. C. Paterson, O.B.E.
Major R. Grierson.	Mr. F. Pooley.
Mr. W. E. Warrilow.	

LIBRARY AND MUSEUM.

The President.

Colonel R. E. Crompton, C.B.	Mr. W. M. Mordey.
Mr. P. V. Hunter, C.B.E.	Sir A. M. Ogilvie, K.B.E., C.B.
Prof. E. W. Marchant, D.Sc.	Mr. C. C. Paterson, O.B.E.

"SCIENCE ABSTRACTS."

The President.

Prof. E. W. Marchant, D.Sc.	Mr. W. M. Mordey.
	Mr. C. C. Paterson, O.B.E.
Dr. A. Russell.	

And	*Representing*
Mr. W. R. Cooper.. } Dr. D. Owen .. }	The Physical Society of London.

SHIP ELECTRICAL EQUIPMENT.

The President.

Mr. J. H. Collie.	Mr. A. P. Pyne.
Mr. B. M. Drake.	Mr. S. G. C. Russell.
Mr. A. Henderson.	Mr. T. A. Sedgwick.
Mr. J. W. Kempster.	Mr. C. H. Wordingham, C.B.E.
Mr. J. F. Nielson.	
Mr. N. W. Prangnell.	

And	*Representing*
Sir W. S. Abel, K.B.E. .. .. } Mr. J. T. Milton .. }	Lloyd's Register of Shipping.
Mr. H. H. Berry .. } Mr. C. Rodgers .. }	British Electrical and Allied Manufacturers' Association.

SHIP ELECTRICAL EQUIPMENT—*contd.*

Mr. T. Carlton ..	Board of Trade.
Mr. W. Cross ..	Electrical Contractors' Association.
Mr. J. Foster King	British Corporation for the Survey and Registry of Shipping.
Mr. J. Lowson ..	Institution of Engineers and Shipbuilders in Scotland. Electrical Contractors' Association of Scotland.
Mr. A. W. Stewart	Institution of Naval Architects.
Mr. H. Walker, O.B.E.	N.E. Coast Institution of Engineers and Shipbuilders.

TERRITORIAL CENTRES.

The President.

Mr. W. E. Burnand.	Prof. E. W. Marchant, D.Sc.
Mr. R. A. Chattock.	Sir W. Noble.
Sir J. Devonshire, K.B.E.	Mr. A. Page.
Mr. R. N. Eaton.	Prof. W. M. Thornton, O.B.E., D.Sc.
Mr. F. Gill, O.B.E.	Mr. W. Walker.
Mr. E. T. Goslin.	Mr. C. H. Wordingham, C.B.E.
Mr. P. V. Hunter, C.B.E.	
Mr. A. C. MacWhirter.	

WIRELESS SECTION.

Professor G. W. O. Howe, D.Sc. (*Chairman*).

The President.

Mr. B. Binyon, O.B.E.	Prof. E. W. Marchant, D.Sc.
Sir Charles Bright, F.R.S.E.	
Mr. R. C. Clinker.	Mr. G. H. Nash, C.B.E.
Dr. W. H. Eccles, F.R.S.	Mr. C. C. Paterson, O.B.E.
Prof. C. L. Fortescue, O.B.E.	Capt. H. J. Round, M.C.
Mr. A. Gray.	Mr. A. A. C. Swinton, F.R.S.
Admiral Sir H. B. Jackson, R.N., G.C.B., K.C.V.O., F.R.S.	Mr. L. B. Turner.
	Mr. C. H. Wordingham, C.B.E.

And	*Representing*
Major J. Erskine-Murray, D.Sc. ..	Air Ministry.
Mr. E. H. Shaughnessy, O.B.E. ..	Post Office.
Lt.-Col. H. Clementi Smith, D.S.O. ..	War Office
Capt. J. S. B. Salmond, R.N. ..	Admiralty.

WIRING RULES.

The President.

Mr. Ll. B. Atkinson.	Mr. S. W. Melsom.
Mr. J. W. Beauchamp.	Mr. J. F. Nielson.
Mr. H. J. Cash.	Mr. A. P. Pyne.
Mr. J. R. Cowie.	Mr. E. Ridley.
Mr. W. Cross.	Mr. C. P. Sparks, C.B.E.
Mr. J. Frith.	Mr. C. H. Wordingham, C.B.E.
Dr. C. C. Garrard.	
Mr. P. V. Hunter, C.B.E.	

And	*Representing*
Mr. J. R. Dick .. } Mr. H. H. Berry .. }	British Electrical and Allied Manufacturers' Association.
Mr. W. F. Bishop..	Cable Makers' Association.
Sir T. O. Callender } Mr. J. F. W. Hooper }	Cable Makers (unofficially).

WIRING RULES –*contd.*

Mr. W. R. Rawlings Mr. S. H. Webb ..	Electrical Contractors' Association.
Mr. E. J. B. Lowden	Electrical Contractors' Association of Scotland.
Mr. B. M. Drake ..	Contractors (unofficially).
Mr. A. C. Cockburn Mr. S. G. C. Russell Mr. A. L. Taylor ..	Fire Offices (unofficially).
Mr. J. Christie .. Mr. F. W. Purse ..	Incorporated Municipal Electrical Association.
Mr. E. T. Ruthven Murray	Incorporated Association of Electric Power Companies.
Mr. O. M. Andrews	Conference of Chief Officials of the London Electric Supply Companies.
Mr. J. M. Crowdy ..	Association of Supervising Electricians.

SECTIONAL COMMITTEES.

Lighting and Power.

The President

Mr. J. R. Beard.	Mr. G. W. Partridge.
Mr. S. E. Fedden.	Mr. W. M. Selvey.
Mr. A. H. W. Marshall.	Mr. C. P. Sparks, C.B.E.
Mr. E. T. Ruthven Murray.	Mr. B. Welbourn.

Mr. W. B. Woodhouse

Electricity in Mines.

The President.

Mr. W. A. Chamen.	Mr. W. C. Mountain.
Dr. C. C. Garrard.	Mr. W. H. Patchell.
Mr. J. A. B. Horsley	Mr. W. M. Selvey.
Mr. P. V. Hunter, C.B.E.	Mr. C. P. Sparks, C.B.E.

Mr. W. B. Woodhouse.

Traction.

The President

Sir J. Devonshire, K.B.E.	Mr. A. H. W. Marshall.
Mr. H. W. Firth.	Mr. G. W. Partridge.
Lt.-Col. F. A. Cortez Leigh.	Mr. J. Sayers.
Mr. F. Lydall.	Mr. R. T. Smith.

Mr. B. Welbourn.

Electro-Chemistry and Electro-Metallurgy.

The President.

Mr. W. A. Chamen.	Mr. C. P. Sparks, C.B.E.
Mr. W. R. Cooper.	Mr. J. Swinburne, F.R.S.
Mr. S. E. Fedden.	and 2 members to be co-opted by the Committee.
Mr. W. M. Mordey.	
Mr. W. M. Morrison	

Telegraphs and Telephones.

The President.

Sir Charles Bright, F.R.S.E.	Mr. F. Gill, O.B.E.
Mr. H. G. Brown.	Mr. H. H. Harrison.
Dr. W. H. Eccles, F.R.S.	Sir W. Noble.
Mr. S. Evershed.	Mr. F. Ryan.
	Mr. J. Sayers.

Representatives of The Institution on Other Bodies.

The following is a list of representatives of the Institution on other bodies and the dates on which they were appointed.

Birmingham Chamber of Commerce:
Mr. S. T. Allen (27 March, 1919).

Bradford Public Libraries Committee:
Mr. T. Roles (27 Feb., 1919).

Bristol University:
Mr. H. F. Proctor (6 Dec., 1917).

British Electrical and Allied Industries Research Association:
Mr. Ll. B. Atkinson (2 April, 1919).
Dr. C. C. Garrard (30 Oct., 1919).
Mr. J. S. Highfield (2 April, 1919).
Mr. C. C. Paterson, O.B.E. (4 Oct., 1917).
Mr. R. T. Smith (30 Oct., 1919).
Mr. C. P. Sparks, C.B.E. (4 Oct., 1917).
Mr. C. H. Wordingham, C.B.E. (3 Oct., 1917).

Sectional Committee on Electric Control Apparatus Research:
Mr. C. H. Wordingham, C.B.E. (22 Nov., 1920).
Major H. C. Gunton (2 Feb., 1921).

British Electrical Development Association:
Mr. R. Hardie (27 Jan., 1921).
Mr. B. Welbourn (27 Jan., 1921).
Mr. C. H. Wordingham, C.B.E. (18 Sept., 1919).

British Engineering Standards Association:
Main Committee:
Col. R. E. Crompton, C.B. (2 April, 1914).
Sir John Snell (2 April, 1914).
Mr. C. H. Wordingham, C.B.E. (26 Feb., 1920).

Sectional Electrical Committee:
Mr. F. Gill, O.B.E. (21 May, 1914).
Mr. J. S. Highfield (21 May, 1914).
Mr. R. T. Smith (21 May, 1914).
Mr. W. B. Woodhouse (19 Dec., 1918).
Mr. C. H. Wordingham, C.B.E. (18 Nov., 1915).

Sectional Committee on British Standards in Colonial and Foreign Trade:
Mr. C. P. Sparks, C.B.E. (26 Oct., 1916).

Sectional Committee on Machine Parts and their Gauging and Nomenclature:
Mr. J. H. Rider (8 Feb., 1917).

Electrical Nomenclature and Symbols Sub-Committee:
Mr. C. C. Paterson, O.B.E. (8 Jan., 1920).

Overhead Transmission Lines Material Sub-Committee:
Mr. C. H. Wordingham, C.B.E. (30 Oct., 1919).

Pipe Flanges Sub-Committee:
Mr. W. M. Selvey (14 April, 1921).

Conference on Standardisation of Ball and Roller Bearings:
Mr. W. M. Selvey (25 July, 1921).

Corrosion Research Committee, Institute of Metals:
Mr. J. S. Highfield (4 Oct., 1917).

Darlington Board of Invention and Research:
Mr. R. M. Longman (15 May, 1919).
Mr. J. R. P. Lunn (15 May, 1919).
Mr. H. G. A. Stedman (15 May, 1919).

Fuel Economy Committee, British Association:
Mr. C. H. Wordingham, C.B.E. (9 Jan., 1919).

Imperial College of Science and Technology, Governing Body:
Mr. W. M. Mordey (30 Oct., 1919).

Imperial Mineral Resources Bureau Conference:
Mr. J. H. Rider (23 Jan., 1919).
Mr. W. B. Woodhouse (23 Jan., 1919).

Copper Committee:
Mr. B. Welbourn (18 Sept., 1919).

Miscellaneous Minerals Committee:
Prof. E. Wilson (18 March, 1920).

International Illumination Commission, British National Illumination Committee:
Prof. W. C. Clinton (13 Dec., 1917).
Mr. K. Edgcumbe (27 Nov., 1913).
Mr. Percy Good (18 Sept., 1919).
Mr. H. T. Harrison (27 Nov., 1913).
Prof. J. T. MacGregor-Morris (27 Nov., 1913

International Scientific Unions:
Committee on International Union on Physics:
Dr. A. Russell (18 March, 1920).

Committee on International Union on Radio-Telegraphy:
Dr. W. H. Eccles (18 March, 1920).
Prof. G. W. O. Howe, D.Sc. (18 March, 1920).
Prof. E. W. Marchant, D.Sc. (18 March, 1920).

International Smoke Abatement Exhibition, 1922:
Mr. J. W. Beauchamp (26 July, 1921).
Mr. J. S. Highfield (26 July, 1921).

Leeds Civic Society:
Mr. E. C. Wallis (27 March, 1919).

Leeds Municipal Technical Library Committee:
Mr. W. B. Woodhouse (19 Dec., 1918).

Metalliferous Mining (Cornwall) School, Governing Body:
Mr. J. S. Highfield (18 Sept., 1919).

Munitions Inventions Department, Nitrogen Products Committee:
Sir John Snell (12 Oct., 1916).

Munitions, Ministry of, Disposal of Surplus Government Property:
Mr. J. S. Highfield (13 Feb., 1919).

National Committee for Physics (Royal Society):
Dr. A. Russell (16 Dec., 1920).

National Committee in Radio-Telegraphy (Royal Society):
Dr. H. W. Eccles, F.R.S. (4 Aug., 1920).
Prof. E. W. Marchant, D.Sc. (4 Aug., 1920).

National Physical Laboratory, General Board:
Mr. Ll. B. Atkinson (21 Oct., 1920).
Mr. C. H. Wordingham, C.B.E. (22 Nov., 1917

Paris Conference on E.H.T. Lines:
Mr. P. V. Hunter, C.B.E. (26 July, 1921).
Mr. E. B. Wedmore (26 July, 1921).
Mr. W. B. Woodhouse (26 July, 1921).

Paris Conference on Weights and Measures:
Sir R. T. Glazebrook, K.C.B., D.Sc., F.R.S. (14 April, 1921).
Dr. A. Russell (14 April, 1921)

Professional Classes Aid Council:
Mr. W. B. Esson (26 July, 1921).

Röntgen Society Advisory Committee for British X-ray Industry:
Dr. W. H. Eccles, F.R.S. (21 Feb., 1918
Mr. J. E. Taylor (21 Feb., 1918).

Royal Engineer Board:
Mr. C. H. Wordingham, C.B.E. (7 April, 1921).

Scientific and Industrial Research Advisory Council, Engineering Committee:
Mr. J. S. Highfield (9 March, 1916).

Scientific Societies, Conjoint Board of:
Mr. C. C. Paterson, O.B.E. (9 Dec., 1920).
Dr. A. Russell (9 Dec., 1920).

Education Committee:
Dr. A. Russell (12 Oct., 1916).

Transport Ministry, Advisory Panel and Committees:
Mr. Ll. B. Atkinson (30 Oct., 1919).
Sir J. Devonshire, K.B.E. (30 Oct., 1919).
Mr. J. S. Highfield (30 Oct., 1919).
Mr. R. T. Smith (30 Oct., 1919).
Sir John Snell (30 Oct., 1919).
Mr. C. P. Sparks, C.B.E. (30 Oct., 1919).
Mr. C. H. Wordingham, C.B.E. (30 Oct., 1919).

War Office Committee on Engineer Organization:
Mr. C. H. Wordingham, C.B.E. (10 April, 1919).

Women's Engineering Society:
Mr. A. P. M. Fleming, O.B.E. (14 April, 1921).

Accessions to the Lending Library.

AITKEN, W. Automatic telephone systems, vol. I, Circuits and apparatus as used in the public services. 4to. 297 pp. *London*, 1921

ANGLO-MEXICAN PETROLEUM COMPANY, LTD. Mex fuel oil. [2nd ed.] 8vo. 225 pp. *London*, 1921

BEHREND, B. A. The induction motor and other alternating current motors. Their theory and principles of design. 2nd ed.
8vo. 295 pp. *New York*, 1921

BRAME, J. S. S. Fuel, solid, liquid and gaseous. 2nd ed. 8vo. 387 pp. *London*, 1920

BROUGHTON, H. H. The electrical handling of materials. A manual on the design, construction and application of cranes, conveyors, hoists and elevators. vol. 2, Structural work. 4to. 307 pp. *London*, 1920

CLAYTON, A. E. Power factor correction. sm. 8vo. 119 pp. *London*, 1921

ECCLES, W. H. Continuous wave wireless telegraphy. pt. 1. 8vo. 414 pp. *London*, [1921]

FLEMING, J. A., *D.Sc., F.R.S.* Fifty years of electricity. The memories of an electrical engineer. 4to. 382 pp. *London*, [1921]

GRANT, L. C. The steam turbo-alternator. Dealing with the various types of turbines, high speed alternators, and their control gear in present day use. 8vo. 276 pp. *London*, 1921

GRAY, A., *F.R.S.* Absolute measurements in electricity and magnetism. 2nd ed. 8vo. 856 pp. *London*, 1921

HOBBS, W. R. P. The arithmetic of electrical measurements, with numerous examples, fully worked. 16th ed., reprinted. Revised and edited by A. R. Palmer. sm. 8vo. 128 pp. *London*, [1919]

JAMIESON, A. Elementary manual of magnetism and electricity. [6th ed. sm. 8vo. 307 pp. *London*, 1905

LANGBEIN, G. Electro-deposition of metals. Translated, with additions, by W. T. Brannt. 8th ed. la. 8vo. 875 pp. *London*, 1920

LEWES, V. B. Oil fuel. sm. 8vo. 262 pp. *London*, [1913]

MORECROFT, J. H. Principles of radio communication. By J. H. M., assisted by A. Pinto and W. A. Curry. 8vo. 945 pp. *New York*, 1921

MOXEY, L. W., *Jr.* The electrical contractor. Principles of cost-keeping and estimating, wiring and illumination calculations, and other technical problems of the business. 8vo. 93 pp. *New York*, 1916

PRING, J. N. The electric furnace. 8vo. 497 pp. *London*, 1921

ROYDS, R. The measurement of steady and fluctuating temperatures. 8vo. 173 pp. *London*, 1921

SCOTT-TAGGART, J. Thermionic tubes in radio-telegraphy and telephony. 8vo. 447 pp. *London*, [1921]

SNELL, *Sir* JOHN F. C. Power house design. 2nd ed. 8vo. 546 pp. *London*, 1921

SYLVESTER, C. Rotary converters, their design, construction and use. sm. 8vo. 57 pp. *London*, [1920]

TIMBIE, W. H., and HIGBIE, H. H. Alternating-current electricity and its applications to industry. First course. [With "Answers to problems"]. 8vo. 544 + 30 pp. *New York*, 1915–1916

WALKER, M. The diagnosing of troubles in electrical machines. 8vo. 461 pp. *London*, 1921

WOOD, L. E. A practical treatise on three-phase induction motors. sm. 8vo. 134 pp. *London*, 1921

THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 30. Jan. 1922. INSTITUTION NOTES. [ISSUED WITH No. 305 OF THE JOURNAL.]

Arrangements for February 1922.

COMMEMORATION MEETINGS.

Date.	*Function.*
1922.	
21 Feb.	Annual Dinner.
21 Feb. to 23 Feb.	Meetings in commemoration of the first meeting of the Society of Telegraph Engineers held on 28th February, 1872. Full particulars will be announced later.

ORDINARY MEETINGS OF THE INSTITUTION.

(Thursdays.)

[To be held at the Institution, Savoy Place, Victoria Embankment, London, W.C. 2, at 6 p.m. (light refreshments 5.30 p.m.).]

Date.	*Author and Title of Paper.*
1922.	
2 Feb.	L. J. Romero and J. B. Palmer: "The Interconnection of Alternating-current Power Stations."
16 Feb.	F. P. Whitaker: "Rotary Converters, with special reference to Railway Electrification."

MEETING OF THE WIRELESS SECTION.

(Wednesday.)

[To be held at the Institution, Savoy Place, Victoria Embankment, London, W.C. 2, at 6 p.m. (light refreshments 5.30 p.m.).]

1 Feb. J. Erskine-Murray, D.Sc., and B. Williams, B.Sc.: "The Determination of the Decrement of a Distant Station by Means of a Coil Aerial."
J. Erskine-Murray, D.Sc., and J. Robinson, Ph.D.: "Directional Transmission of Electromagnetic Waves for Navigational Purposes."

INFORMAL MEETINGS.

(Mondays.)

[To be held at the Institution, Savoy Place, Victoria Embankment, London, W.C. 2, at 7 p.m.]

Date.	*Author and Title of Paper.*
1922.	
6 Feb.	Discussion on "Some Practical Applications of the Thermionic Valve" (opened by Mr. J. Joseph).
20 Feb.	Discussion on "The Emergency Use of Oil Fuel during the Recent Coal Strike" (opened by Mr. E. F. Hetherington).

MEETINGS OF TERRITORIAL CENTRES AND SUB-CENTRES.

Date.	*Place of Meeting.*	*Author and Title of Paper.*
1922.		
1 Feb.	Birmingham	Dr. S. P. Smith: "Single- and Three-phase Commutator Motors with Shunt and Series Characteristics." (Lecture, to be followed by a discussion.)
2 Feb.	Middlesbrough	C. T. S. Arnett: "Electricity applied to Household Purposes."
6 Feb.	Cardiff	Dinner of the Western Centre. Visit of the President, Mr. J. S. Highfield.
7 Feb.	Manchester	L. J. Romero and J. B. Palmer: "The Interconnection of Alternating-current Power Stations."
10 Feb.	Dublin	R. D. Archibald: "A Method of Regulating the Voltages on the Two Sides of a Three-wire D.C. System equalized by Static Balancers."
13 Feb.	Dundee	J. W. Beauchamp: "Publicity and Electrical Development."
13 Feb.	Newcastle	F. P. Whitaker: "Rotary Converters, with special reference to Railway Electrification."
14 Feb.	Glasgow	Major J. Erskine-Murray: "The Use of Wireless, Past and Future." (Lecture.)
14 Feb.	Leeds	L. J. Steele and H. Martin: "The Cyc-Arc Process of Automatic Electric Welding."
14 Feb.	Loughborough	Informal Discussion on "Mercury Arc Rectifiers."
15 Feb.	Sheffield	(To be announced later.)
20 Feb.	Liverpool	Dr. S. S. Richardson: "An Oscillograph Investigation of the Gulstad Relay."
21 Feb.	Manchester	Discussion on "The Utilization of Waste Heat from Electrical Generating Stations," with introductory papers by Mr. C. I. Haden and Mr. F. H. Whysall.
22 Feb.	Birmingham	F. P. Whitaker: "Rotary Converters, with special reference to Railway Electrification."
27 Feb.	Newcastle	Discussion on "Starters," with introductory papers:— J. Anderson: "Electric Motor Starters." W. Wilson, B.E., M.Sc.: "Some Notes on the Design of Liquid Rheostats."
28 Feb.	Glasgow	Dinner of the Scottish Centre.
28 Feb.	Leeds	Exhibition of the cinematograph films shown in London on the 12th January.

LONDON STUDENTS' SECTION.

MEETINGS.

(Fridays.)

[To be held at The Institution, Savoy Place, Victoria Embankment, W.C. 2, at 7 p.m.]

Date.	*Author and Title of Paper.*
1922.	
3 Feb.	N. A. Allen: "The Carbon Arc Crater."
17 Feb.	(To be announced later.)

Visits.

Date.		*Subject to be Visited.*
1922.		
11 Feb.	(Morning)	G.P.O. Laboratory, Dollis Hill.
	(Afternoon)	Central Telegraph Office.
24 Feb.		The Avonbank Co., Bayes.

The above visits are open *only* to Students of the Institution. Students wishing to attend must notify Mr. H. J. Howard, 115, Queen's Road, Wimbledon, S.W. 19, at least 10 days before the visit. When the number of the party is limited, the Committee reserve the right to decide, by ballot or otherwise, which Students may attend.

British Engineering Students.

The President has pleasure in bringing the following letter to the notice of the Student members of the Institution:

SOCIÉTÉ DES INGÉNIEURS CIVILS DE FRANCE
(BRITISH SECTION).

45, Great Marlborough Street,
London, W. 1.
13th December, 1921.

THE PRESIDENT,
The Institution of Electrical Engineers.

DEAR SIR,

It may interest your members to know that French engineering firms of Lorraine district (rolling stock, railway material, etc.) having kindly consented to accept, for periods of 2 or 3 months, a few British engineering students during their summer holidays, applications *in writing*, stating age, qualifications, and giving references, will be received (until further notice) by the Hon. Secretary, British Section of Société des Ingénieurs Civils de France, 45, Great Marlborough-street, London, W. 1.

The students will not receive any salary and will make their own arrangements for the journey, board and lodgings. Local members of the Société will give advice in these matters if desired. The students will, in their own interests, undertake to submit to the same discipline and working hours as their French colleagues on the works' staff.

Some knowledge of the French language is advisable.

I am, etc.,
(Signed) THE PRESIDENT,
La Société des Ingénieurs Civils
de France.

Wireless Aerial on Institution Building.

Arrangements are being made for the erection of a permanent aerial on the roof of the Institution building.

Library.

The Council have decided to keep the Library open until 9.30 p.m. on the evenings on which there are Ordinary Meetings of the Institution, Informal Meetings, and Meetings of the Wireless or Students' Sections (see *Institution Notes*, No. 29, page 2, December 1921).

Ronalds Library.

Mr. J. E. Montgomrey, Mr. C. C. Paterson, O.B.E., and Mr. A. A. C. Swinton, F.R.S., have been appointed additional trustees of the Ronalds Library; the other trustees are Mr. J. C. Carter, Mr. R. Carter, Colonel R. E. B. Crompton, C.B., Sir R. T. Glazebrook, K.C.B., D.Sc., F.R.S., and Mr. B. Ronalds.

Electricity in Working-Class Dwellings.

A Report (E.D.A. No. 167) on "The Use of Electricity in Working-Class Dwellings" has been prepared for the British Electrical Development Association by Messrs. G. Blair Imrie and T. G. Angell, architects.

The Report contains plans showing the comparison between the arrangement and equipment of a typical working-class dwelling (Cottage Plan No. 178 of the Ministry of Health) provided for the use of coal only, and coal with gas or electricity. An important saving can be effected in the cost of construction by the omission of certain fireplaces and chimneys, which becomes possible where electricity is employed for cookery, and the provision of heat in all positions where that method can be economically used.

The saving, after providing equipment, and without any allowance for the lighting installation, in the "All Coal" house, is shown to be sufficient to cover the electrical installation and produce the "All Electric" house for practically the same expenditure as the "All Coal" house, whilst cost is reduced by £34 in comparison with the "All Gas" house.

An introductory note to the Report states that: "The labour-saving and hygienic equipment of the electric home need not increase its first cost, and where a supply of electricity can be obtained at rates which are fairly competitive with gas or fuel there can be no good reason for delaying the construction of houses on the principles outlined in this Report. The electric method will undoubtedly become general in the home within a time which will be short compared with the life of a house, and failure to take advantage of this development can only result in dwellings becoming relatively out-of-date and of depreciated value in the near future."

Copies of the Report can be obtained from Mr. J. W. Beauchamp, Director and Secretary to the Association, 84, Kingsway, W.C. 2, price 10s. each.

International Commission on Illumination.

The Council have received from the representatives of the Institution on the National Illumination Committee of Great Britain and the International

Commission on Illumination a Report, the substance of which is as follows :

An International Commission on Photometry was appointed in 1903 to determine rules to be followed in testing incandescent gas lights.

In 1911 this Commission, having decided to widen its scope, invited the electrical interests to join, and in 1913 at a meeting held in Berlin a new Commission to be called the " International Commission on Illumination " was formed and statutes were adopted by representatives of the following countries : Great Britain, France, United States, Italy, Germany, Austria, Belgium, Holland, and Switzerland. By these statutes, the Commission was formally constituted to study all questions connected with the art of illumination and of the sciences related thereto, and to establish by suitable means international agreement on questions of illumination.

The British delegates at that meeting were : Mr. W. J. Butterfield, Dr. Colman, Mr. W. Duddell, F.R.S., Mr. K. Edgcumbe, Mr. L. Gaster, Mr. le Maistre, and Mr. C. C. Paterson.

M. Th. Vautier (France) was elected President of the new Commission and Dr. Hyde, Dr. Bunte, and Dr. Kusminsky, Vice-presidents, and Mr. C. C. Paterson, Hon. Secretary.

The British National Committee on Illumination was formed under the title of " The National Illumination Committee of Great Britain " to represent Great Britain and Ireland on the International Commission. The Rules of the British Committee fix its composition at not more than five representatives of the Institution of Electrical Engineers, five of the Institution of Gas Engineers, five of the Illuminating Engineering Society, and two of the National Physical Laboratory. Unfortunately, the war intervened and prevented the British Committee and the Commission from carrying on effectively the objects for which they were constituted. In 1919, the British Committee again met with Mr. A. P. Trotter as President. In 1920, Mr. Trotter was unfortunately unable to continue the work and Major Kenelm Edgcumbe, one of the I.E.E. nominees, was elected President, and Mr. C. C. Paterson Vice-president.

A number of meetings of the British Committee were held during 1921, and a meeting of the International Commission was held in Paris in July 1921. The Committee nominated the following to attend the meeting as the British delegates :—

Major K. Edgcumbe Mr. Percy Good	representing the I.E.E.
Mr. Leon Gaster Mr. A. P. Trotter	representing the Illuminating Engineering Society
Mr. Robert Watson	representing the Institution of Gas Engineers.
Dr. E. H. Rayner Mr. J. W. T. Walsh	representing the National Physical Laboratory. And

Mr. C. C. Paterson as Honorary Secretary of the International Commission.

The delegates on behalf of the British Committee presented a proposal to the International Commission in regard to the unit of candle power, which, with slight modifications, was accepted by the Commission as follows :—

> " That the International Commission on Illumination shall officially adopt as the unit of candle power the ' International Candle ' as defined by the three national standardizing laboratories of France, Great Britain and America in 1909. This unit has been preserved by means of incandescent electric lamps by these laboratories which remain charged with its preservation.'

These laboratories are the Laboratoire Central d'Electricité, Paris, the National Physical Laboratory, Teddington, and the Bureau of Standards, Washington.

The delegates on behalf of the British Committee also presented proposals for photometric definitions and units. These proposals were based on definitions of luminous radiation and luminous source, and a complete set of definitions had been built up by the following Sub-Committee :—Major K. Edgcumbe, Mr. J. W. T. Walsh, Prof. J. T. MacGregor-Morris, and Mr. P. Good. In the opinion of the British Committee they represented a series of terms, definitions and units which were fundamentally logical and conformed sufficiently nearly to present practice to justify adoption.

Dr. Kenelly presented the American proposals, which had the advantage of having been made public some two years previously, and after full discussion the British delegates accepted substantial modifications to their proposals as they found it would be impossible to get international agreement unless they did so.

The Sub-Committee were then requested by the British National Committee to review their proposed definitions in the light of the Paris decisions and this they did, with the result that the attached set of definitions was drawn up by them and subsequently approved by the British National Committee. It is hoped that their general adoption will be authorized for papers published by the Institution, and that they will receive general adoption in English literature.

In addition to the proposals already referred to as being presented by the British Committee, the following Reports were also presented to the Commission :—

Report on Primary Standards of Light. Report on Nomenclature. Report on Light Filters. Report on Heterochromatic Photometry. Report on Relative Visibility Function. Report on Automobile Headlights. Report on Lighting Legislation.	Presented by the United States Committee.
Report on Properties of the Normal Eye.	Presented by the Italian Committee.
Report on Heterochromatic Photometry. Lighting Rules from the point of view of Security and Hygiene	Presented by the French Committee.

The question of Industrial and School Lighting was dealt with in the following papers :—

"A short summary of Developments on Industrial Lighting."
"Lighting Legislation in the United States."
"A Method of comparing Lighting from a Subjective Point of View in Workshops and Factories."
"Lighting of Workshops and Factories."

As a result of the discussions arising out of these papers, it was proposed that each National Committee should keep in touch with the authorities appointed to issue regulations, and a Sub-committee of the International Commission under the Presidency of Dr. Sharp was appointed to study the subject.

The question as to the possibility of the Commission issuing a bibliography of illumination every year was discussed but no definite action was taken.

The International Commission appointed an Editing Committee as follows :

English Language :—Major Kenelm Edgcumbe, to represent both the United States and Great Britain.
French Language :—MM. Laporte and Blondin.

The following officers were appointed for the ensuing three years :—

President :—Dr. E. P. Hyde.
Vice-presidents :—M. F. Rouland (France), M. G. Semenza (Italy), and Major K. Edgcumbe (Great Britain).
Hon. Secretary and Treasurer :—Mr. C. C. Paterson.

It was further decided that the annual subscription to be paid by each country should be based on its population.

The date of the next Plenary Meeting was provisionally fixed for 1924 in New York.

(Signed) KENELM EDGCUMBE,
PERCY GOOD.

DEFINITIONS AND UNITS APPROVED BY THE NATIONAL ILLUMINATION COMMITTEE OF GREAT BRITAIN.

(1) *Luminous Flux* is the rate of passage of radiant energy evaluated according to the luminous sensation produced by it. Since for all practical photometric purposes the velocity of light may be regarded as constant, luminous flux may be treated as an entity and is so treated in the definitions which follow.

(2) The unit of Luminous Flux is the *Lumen*. It is equal to the luminous flux emitted per unit solid angle by a uniform point source of one international candle.

(3) A *Luminous Source* is one which emits luminous flux. A point source is one which subtends a negligibly small angle at the point from which it is observed.

(4) The *Luminous Intensity*, or *Candle Power* of a point source in any direction is the luminous flux emitted in that direction by the source per unit solid angle.

(5) The unit of Luminous Intensity or Candle Power is the *International Candle*. This unit is the outcome of agreement arrived at by the three National Standardizing laboratories of France, Great Britain, and the United States of America in 1909. The unit has since that time been preserved by these laboratories by means of electric incandescent lamps, and the laboratories are still responsible for its preservation.

(6) The *Average Candle-Power* of a luminous source is the average value of the candle-power in all directions (this term is recommended in place of the term "mean spherical candle-power"). When it is desired to define the average value of the candle-power in a given zone or given hemisphere, this should be specified thus : "Average candle-power (upper hemisphere)."

(7) The *Illumination* at a surface is the luminous flux reaching that surface per unit area.

(8) The practical unit of illumination is the *Lux*. It is the illumination at the surface of a sphere of one metre radius due to a uniform point source of one candle placed at its centre, i.e. it is equal to one lumen per square metre.

If the centimetre be taken as the unit of length the unit of illumination is the lumen per square centimetre known as the "phot." If the foot is taken as the unit of length, the unit of illumination is the lumen per square foot known as the "foot-candle."

1 foot-candle = 10·764 lux = 1·0764 milli-phot.

(9) The *Brightness* of a surface in a given direction is the candle-power per unit projected area of the surface in that direction. It is expressed either in candles per square millimetre or per square metre.

(10) The *Specific Output* of an electric lamp is the ratio of the luminous flux to the power applied. It is expressed in lumens per watt. The specific output of a source depending on combustion is similarly expressed in lumens per British thermal unit per hour.

(11) The *Specific Consumption* of an electric lamp is the ratio of the power input to the average candle power. It is expressed in watts per average candle. The specific consumption of a source depending on combustion is similarly expressed in British thermal units per hour per average candle.

(12) The *Reflection Ratio* of a surface for radiant energy of given spectral distribution is the ratio of the luminous flux leaving the surface to the luminous flux incident thereat, both being expressed in lumens (this quantity has hitherto been termed the "coefficient of reflexion").

(13) The *Absorption Ratio* of a body for radiant energy of given spectral distribution is the ratio of the luminous flux absorbed by the body, to the luminous flux incident thereat, both being expressed in lumens.

(14) The *Transmission Ratio* of a body for radiant energy of a given spectral distribution is the ratio of the luminous flux passing through the body, to the luminous flux incident thereat, both being expressed in lumens.

THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 31. Feb. 1922. INSTITUTION NOTES. [ISSUED WITH No. 306 OF THE JOURNAL]

Arrangements for March 1922.

ORDINARY MEETINGS OF THE INSTITUTION.

(Thursdays.)

[To be held at the Institution, Savoy Place, Victoria Embankment, London, W.C. 2, at 6 p.m. (light refreshments 5.30 p.m.).]

Date. 1922.	*Author and Title of Paper.*
2 Mar.	Discussion on "Starters," with introductory papers by: C. H. Wordingham, C.B.E.: "The B.E.S.A. Specifications on Starters." J. Anderson: "Electric Motor Starters." W. Wilson, B.E., M.Sc.: "Some Notes on the Design of Liquid Rheostats."
16 Mar.	J. G. Hill: "Phantom Telephone Circuits, and Combined Telegraph and Telephone Circuits, worked at Audio Frequencies."
30 Mar.	R. Borlase Matthews: "Applications of Electricity to Agriculture."

MEETING OF THE WIRELESS SECTION.

(Wednesday.)

[To be held at the Institution, Savoy Place, Victoria Embankment, London, W.C. 2, at 6 p.m. (light refreshments 5.30 p.m.).]

Date. 1922.	*Author and Title of Paper.*
1 Mar.	E. B. Moullin, M.A., and L. B. Turner, M.A.: "The Thermionic Triode as Rectifier."

INFORMAL MEETINGS OF THE INSTITUTION.

(Mondays.)

[To be held at the Institution, Savoy Place, Victoria Embankment, W.C. 2, at 7 p.m.]

Date. 1922.	*Subject.*
6 Mar.	Discussion on "E.H.T. Cable-Testing" (opened by Mr. E. Ambrose).
20 Mar.	(Subject to be announced later.)

MEETINGS OF TERRITORIAL CENTRES AND SUB-CENTRES.

Date. 1922.	*Place of Meeting.*	*Author and Title of Paper.*
2 Mar.	Middlesbrough	Exhibition of the cinematograph films shown in London on the 12th January.
6 Mar.	Bristol	L. H. A. Carr: "Induction-type Synchronous Motors."
7 Mar.	Derby	J. F. Driver: "The X-Ray Examination of Materials."
10 Mar.	Dublin	Prof. R. Stanley: "Wireless Communications in the Campaign in France."
10 Mar.	Manchester	Exhibition of the cinematograph films shown in London on the 12th January.
13 Mar.	Dundee	J. Anderson: "Electric Motor Starters." L. H. A. Carr: "Induction-type Synchronous Motors."
13 Mar.	Newcastle	Visit of the President, Mr. J. S. Highfield.
14 Mar.	Edinburgh	E. S. Byng: "Telephone Line Work in the United States."
14 Mar.	Leeds	L. Romero and J. B. Palmer: "The Interconnection of Alternating-current Power Stations."
14 Mar.	Middlesbrough	Visit of the President, Mr. J. S. Highfield.
15 Mar.	Birmingham	J. Anderson: "Electric Motor Starters."
15 Mar.	Sheffield	F. Langley: "Notes on the Practical Operation of E.H.T. Protective Gear."
20 Mar.	Liverpool	L. Romero and J. B. Palmer: "The Interconnection of Alternating-current Power Stations."
21 Mar.	Manchester	J. Frith: "Specifications and Estimates" (Informal Meeting).
27 Mar.	Newcastle	J. A. Kuyser: "Protective Apparatus for Turbo-Generators."
28 Mar.	Leeds	(To be announced later.)
28 Mar.	Loughborough	A. H. Seabrook: "The Future Aspect of Power Generation."
30 Mar.	Middlesbrough	W. R. Cooper: (Subject to be announced later).

LONDON STUDENTS' SECTION.

MEETINGS.

(Fridays.)

[To be held at the Institution, Savoy Place, Victoria Embankment, London, W.C. 2, at 7 p.m.]

Date. 1922.	*Author and Title of Paper.*
17 Mar.	C. C. H. Wade: "The Electron Theory."
31 Mar.	Address by the President, Mr. J. S. Highfield.

VISITS.

Date. 1922.	*Works to be Visited.*
10 Mar. (Afternoon)	Siemens Bros. & Co., Ltd., Woolwich.
25 Mar. (Morning)	British Thomson-Houston Co., Ltd., Willesden.
(Afternoon)	L. & N.W. Rly. Power House, Stonebridge Park.*

The above visits are open *only* to Students of the Institution. Students wishing to attend must notify Mr. H. J. Howard, 115, Queen's Road, Wimbledon, S.W. 19, at least 10 days before the visit.

* Students desiring to take part in this visit must give their nationality when applying for a ticket.

Associate Membership Examination.

Provided that a sufficient number of candidates make application, it is proposed to hold the Associate Membership Examination in London and at other places (at home and abroad) in April next. Particulars can be obtained from the Secretary of the Institution.

North-Western Centre.

The Council have acceded to a request from the North-Western Centre for the Centre to be extended so as to include the counties of Carnarvon, Denbigh, Merioneth, Montgomery, the remainder of the County of Flint (part of which is already in the Centre), and the Island of Anglesea.

British Electrical Development Association.

Mr. H. J. Cash has been nominated to serve on the Council of the Association as one of the Institution's representatives, in place of Mr. B. Welbourn, who is unable to attend the meetings.

Informal Meetings.

The following Informal Meetings have been held :—

25TH INFORMAL MEETING (5TH DECEMBER, 1921).

Chairman : Mr. J. R. Bedford.

Subject of Discussion : "Some Recent Developments in the Design of A.C. Instruments" (introduced by Mr. C. L. Lipman).

Speakers : Major K. Edgcumbe, Messrs. H. Brazil and A. T. Kemsley.

26th INFORMAL MEETING (9TH JANUARY, 1922)

Chairman : Mr. A. B. Eason.

Subject of Discussion : "Co-operative Advertising in Relation to the Electrical Industry" (introduced by Mr. J. W. Beauchamp).

Speakers : Messrs. A. F. Harmer, W. E. Rogers, W. L. Wreford, A. B. Eason, F. T. Hall, W. J. Minton, E. R. Morton, A. G. Hilling, E. W. Moss, M. D. Hart, A. G. Whyte, C. E. Sexton, W. E. Warrilow, H. T. Young, R. W. Hughman, and H. J. Groves Webb.

27TH INFORMAL MEETING (23RD JANUARY, 1922).

Chairman : Major R. Grierson.

Subject of Discussion : "Electric Vehicles, Present and Future" (introduced by Mr. R. J. Mitchell).

Speakers : Messrs. A. W. Blake, W. E. Rogers, N. Murphy, F. Jackson, A. W. Epston, A. F. Harmer, W. J Minton, W. E. Warrilow, A. G. Whyte, W. R. Montgomery. E. G. Kennard, G. Y. Fraser, E. A. Scarborough, and Major R. Grierson.

28TH INFORMAL MEETING (6TH FEBRUARY, 1922).

Chairman : Mr. A. F. Harmer.

Subject of Discussion : "Some Practical Applications of the Thermionic Valve" (introduced by Mr. J. Joseph).

Speakers : Messrs. P. Dunsheath, S. R. Mullard, P. M. Baker Professor C. L. Fortescue, Messrs. L. B. Miller, E. Kilburn Scott, W. S. Tucker, D.Sc., P. R. Coursey, C. A. Newell, C. Robinson, H. G. Bell, and A. F. Harmer.

Electrical Research.

The Secretary of the Institution has received from the British Electrical and Allied Industries Research Association the following :

QUARTERLY REVIEW OF PROGRESS (JANUARY, 1922).

SECTION A : FIBROUS INSULATING MATERIALS.

Fabrics, untreated and treated.—A specification for the investigation of varnished fabrics has now been drafted, and the clauses covering mechanical tests are being proved by experimental trial. Arising out of the development of tests on electric strength, it has been found desirable to formulate a series of tests applicable to all the conditions which arise in the testing of materials with a fibrous base, and it is hoped later that these may form the basis for the development of a series of standard tests for all kinds of insulating materials. All the leading manufacturers are represented on the Committee controlling this work.

Papers, untreated.—A specification has now been completed giving directions for the study of untreated papers, and including much needed definitions of the materials and terms employed. This publication is in the printers' hands and will be issued to members this month. A report is in preparation giving the results of the experimental work which has preceded the production of this document.

Hard fibres and boards.—Specifications have now been drafted for the study of materials in the pressboard, vulcanized fibre and varnish-paper groups, and the clauses are being verified experimentally. The specification for the pressboard group has been approved and is being prepared for the printers. A report is in preparation on the research done.

Varnishes.—A committee is now being formed for research on the varnishes used for the treatment of papers and fabrics, and the co-operation of manufacturers and experts is being sought.

SECTION B : COMPOSITE INSULATING MATERIALS.

A publication has been prepared embodying the methods of test developed by the Association for the investigation and improvement of the characteristics of all the materials in this class, and will be issued to members at once. A complete series of mechanical and electrical tests is provided, including tests for tool wear and chipping. Tests, however, for inflammability, flash point and fire resistance are still under consideration, as also tests on dielectric losses, action of solvents, and surface breakdown. A comprehensive report on the former is already to hand.

SECTION C : PORCELAIN.

Arrangements have been completed for the researches on porcelain to be carried out at Manchester University

and the National Physical Laboratory, and two assistants have been engaged under an experienced investigator and are now fully occupied.

Section D : Mica.

A report has been prepared for members on the results of investigations on the use of mica and micanite for commutators and mica for condensers. During the course of this work, note has been taken of those features in which there has been found a general lack of physical data, and research has been commenced on fundamental constants and the incidence of particular characteristics in particular classes of mica. Arrangements have been made for the publication of a large amount of data obtained by the Electrical Research Committee.

The manufacture of micanite is also under consideration, and manufacturers and users have been invited to furnish information based on their experience.

Section E : Insulating Oils.

Specification for insulating oils.—The Association is co-operating with the B.E.S.A. in completing this specification, and further experimental work has been done. Substantial agreement has now been reached, and the B.E.S.A. has referred a proposed draft for final consideration by the Association.

Researches on electric strength and resistivity.—Further consideration has been given to the way in which water, dust of various kinds, and sludge and solid products produced by arcing, cause deterioration of insulating properties, and the best method of revising present information. Consideration has been given to the use of centrifugal apparatus as an instrument of research. Progress can be made only by further refinements in method.

Other researches.—Researches on thermal transference, latent and specific heat, thermal resistivity and vapour pressure have been continued at the N.P.L. Work on catalysers and on analysis of deposits is also in hand.

Section F : Conductors.

Heating of buried cables.—Attention is now being given to intermittent and overload ratings. Some tests have been made on the effect of intermittent loading, and typical load curves obtained from power station engineers are being analysed. Based on data already to hand, recommendations have been drafted dealing with the intermittent rating of cables used on ships.

Further study has been made of the distribution of temperature in the soil due to heating by buried cables, with a view to allowing for surface phenomena, effect of depth of laying, and method of laying, and as a check on mathematical calculations.

Overhead line materials.—The standard single, **A** and **H** poles, inserted to different depths, have now been tested and full records obtained of deflection at different loads and of performance. Photographic records of the tests were taken with a cinema camera to enable the action to be studied in detail at leisure, and a report is in preparation.

Tests on long lengths of overhead line wires and cables are being pushed to completion.

Section G : Electric Control Apparatus.

Phenomena of switching and arcing.—The short-circuit characteristics of the large alternator at Carville power station which will be used for the researches on oil circuit breakers have been studied and further data is being obtained for the accurate estimation of the instantaneous values of the self-induction, and the effects of cross magnetization and demagnetization. Devices are under development for controlling the instant at which the circuit is closed and broken. Special variable reactances and resistances are being constructed arranged to give complete control of the power factor and energy flow. The adjustable model switch has been completed and arrangements on site are well in hand.

Meanwhile the executive committee has studied in detail the critical survey of the state of knowledge on the phenomena in question, and members have furnished additional information of value.

Mining switchgear.—Further progress has been made in studying the pressure developed in closed chambers, and a workshop method of testing has been devised.

Heavy duty fusible cut-outs.—New investigations have been made on the behaviour of a large battery under short-circuit conditions which will be of value in specifying and interpreting tests on fusible cut-outs. Preliminary tests on fuses have been made, and as soon as the method of test has been proved the complete series of makers' samples of British Standard ordinary duty fusible cut-outs will be subjected to performance tests.

D.C. circuit breakers.—Preliminary observations have disclosed unexpected difficulties in determining the physical constants of power circuits under short-circuit conditions. These are being analysed and check tests devised. It is hoped to secure the loan of suitable apparatus, failing which the special apparatus built for the researches on oil circuit breakers will be utilized as soon as it can be released.

Resistivity of joints and contacts.—A résumé of recent investigations carried out abroad has been received and studied. A report on experimental work carried out at the N.P.L. is now due.

Section H : Corrosion of Metals.

A report has now been prepared giving in a condensed form the conclusions reached as the result of several years' investigations, and containing recommendations based thereon. The issue of this report should go far to remove much misconception and to assist engineers responsible for the maintenance of condensers and the design of condensers to meet onerous conditions.

Section J : Turbines.

The Association is awaiting reports on the work already done on blading. Further attention has been given to the development of new programmes.

Section K : Synthetic Resins.

Close study has been made of the possibilities of developing in this country the production of raw materials from which the synthetic resins can be produced, and to methods of ensuring supplies.

Agreement has now been reached on the tests to which the finished products should be subjected in their various forms, and work on the varnish-paper group has been commenced. The collection of representative samples from all sources is well advanced.

Further study has been given to the requirements of Government Departments, and it is hoped to issue a report to manufacturers shortly.

SECTION L: DIELECTRICS IN GENERAL.

Dielectric losses.—This Section has now developed an extensive programme of research to be carried out at the N.P.L., commencing with low voltages and low and audio frequencies. Numerous samples of representative modern insulating materials have been obtained, and new methods of investigation are under development. Consideration is also being given to the development of methods of investigation at high voltages and at radio frequencies.

Thermal resistivity.—Experimental work on the thermal resistivity of insulating materials employed in sheet form is now in hand and methods have been developed for testing built-up insulation as used in the insulation of high-voltage apparatus, so that the effect of different methods of construction and defects in manufacture may be investigated.

Accessions to the Reference Library.

ANGLO-MEXICAN PETROLEUM COMPANY, LTD. Mex fuel oil. 2nd ed. 8vo. 225 pp. *London*, 1921

BARBILLON, L. Leçons sur le fonctionnement des groupes électrogènes en régime troublé. Perturbations—Régulation—Asservissement—Compensation. 8vo. 308 pp. *Paris*, 1915

BISACRE, F. F. P. Applied calculus. An introductory textbook. 8vo. 460 pp. *London*, 1921

BLOCH, L. Précis d'électricité théorique. 8vo. 482 pp. *Paris*, 1919

BOARD OF TRADE. Final report of the Water Power Resources Committee. fol. 178 pp. *London*, 1921

BOURGUIGNON, P. Essais des machines à courant continu et alternatif, suivi des règlements actuellement publiés conçernant les essais des machines. 8vo. 108 pp. *Paris*, 1907

BRITISH SCIENCE GUILD. A catalogue of British scientific and technical books covering every branch of science and technology carefully classified and indexed. Prepared by a Committee of the British Science Guild. 8vo. 394 pp. *London*, 1921

ELECTRICAL CONTRACTORS' ASSOCIATION, THE. The electrical contractors' year book, 1921–1922. sm. 8vo. 274 pp. *London*, 1921

ELECTRICITY (SUPPLY) ACT, 1919. Inquiry into the area proposed to be included in the London and Home Counties Electricity District before the Electricity Commissioners. [Minutes of evidence, June 14–July 29, 1921]. fol. 881 pp. *London*, 1921

FLEMING, A. P. M., and PEARCE, J. G. Research in industry. The basis of economic progress. 8vo. 260 pp. *London*, 1922

GRAY, A. Absolute measurements in electricity and magnetism. 2nd ed. 8vo. 856 pp. *London*, 1921

HALL, B. J. Blue printing and modern plan copying. 8vo. 139 pp. *London*, 1921

KRAMER, J. B. Radiations from slow-radium. With a note on their therapeutic value by J. Hall-Edwards. 8vo. 105 pp. *London*, 1921

MANVILLE, O. Les découvertes modernes en physique. 1. Electricité et matière. 2. Les ions et les électrons dans la théorie des phénomènes physiques.—La matière et l'éther. 8vo. 464 pp. *Paris*, 1909

MERCIER, G. Gas engine plants. With special reference to their use as prime movers in small electricity generating stations. [Paper read before the Fourth Year's Convention, Municipal Association of Electrical Engineers, 14th Sept., 1920]. 8vo. 18 pp. *Pretoria*, [1920]

MITTELL, B. E. G. Continuous-wave wireless telegraphy. A non-mathematical introduction to the subject of wireless telegraphy from the engineer's point of view. sm. 8vo. 114 pp. *London*, 1922

MUNRO, D. S. The practice of electrical wiring. Revised ed. sm. 8vo. 278 pp. *London*, 1921

PARLIAMENTARY PAPERS. Report of Wireless Telegraphy Commission. [Cmd. 1572]. 8vo. 18 pp. *London*, 1922

PHILIPPI, W. Elektrische Fördermaschinen. 8vo. 312 pp. *Leipzig*, 1921

POMEY, J. B. Introduction a la théorie des courants téléphoniques et de la radiotélégraphie. Avec une préface de A. Blondel. 8vo. 523 pp. *Paris*, 1920

PRIESTLEY, R. E. The Signal Service in the European War of 1914 to 1918. (France). Published by the Secretary, The Institution of Royal Engineers, and by the Signals Association. 8vo. 371 pp., 20 pl. *Chatham*, 1921

RIGHI, A. I fenomeni elettro-atomici sotto l'azione del magnetismo. Narrazione di ricerche sperimentali sui fenomeni elettrici prodotti nel campo magnetico. 8vo. 451 pp. *Bologna*, [1918]

WALKER, M., *D.Sc.* The diagnosing of troubles in electrical machines. la. 8vo. 461 pp. *London*, 1921

WALTER, L. H. Directive wireless telegraphy: direction and position finding, etc. sm. 8vo. 136 pp. *London*, 1921

WEBER, J. Beschreibung des Luftelektrophors. Nebst angehängten neuen Erfahrungen, neuen Instrumenten, einem Unterrichte von Zubereitung der brennbaren Luft, und verschiedener Versuche mit derselben. Neueste mit der Beschreibung der elektrischen Lampe vermehrte Auflage. sm. 8vo. 86 pp., 3 pl. *Augsburg*, 1779

WHEELER, S. G. Entropy as a tangible conception. An elementary treatise on the physical aspects of heat, entropy, and thermal inertia for designers, students, and engineers, and particularly for users of steam and steam charts. 8vo. 76 pp. *London*, 1921

WHO'S WHO IN ENGINEERING, 1921–22. Edited by J. E. Sears. la. 8vo. 757 pp. *London*, [1921]

WILLIAMS, S. R. The magnetic-mechanical analysis of cast iron. [Reprint from the Proceedings of the American Soc. for Testing Materials, Philadelphia, vol. 19, pt. 2, 1919]. 8vo. 6 pp. *n.p., n.d.*

WYER, S. S. Salient features of electric cooking, electric hot water heating and electric house heating. 8vo. 31 pp. *Columbus, Ohio*, 1921

THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 32. March 1922. INSTITUTION NOTES. [ISSUED WITH No. 307 OF THE JOURNAL.]

Arrangements for April and May 1922.

ORDINARY MEETINGS OF THE INSTITUTION.

(Thursdays.)

[To be held at The Institution, Savoy Place, Victoria Embankment, London, W.C. 2, at 6 p.m. (light refreshments 5.30 p.m.).]

Date. 1922.	*Author and Title of Paper.*
6 Apr.	Adjourned Discussion on Mr. R. Borlase Matthews's paper.
27 Apr.	J. A. Kuyser: "Protective Apparatus for Turbo-Generators."
18 May	Sir E. Rutherford, K.B.E., F.R.S.: "Electricity and Matter" (Thirteenth Kelvin Lecture).
25 May	Annual General Meeting.

MEETINGS OF THE WIRELESS SECTION.

(Wednesdays.)

[To be held at The Institution, Savoy Place, Victoria Embankment, London, W.C. 2, at 6 p.m. (light refreshments 5.30 p.m.).]

Date. 1922.	*Author and Title of Paper.*
5 Apr.	Capt. J. H. Whittaker-Swinton, R.E. (T.F.): "The Provision of Power for Wireless Telegraphy."
3 May	(Subject to be announced later.)

MEETINGS OF TERRITORIAL CENTRES AND SUB-CENTRES.

Date. 1922.	*Place of Meeting.*	*Author and Title of Paper.*
3 Apr.	Swansea	R. J. Mitchell: "Electric Vehicles" (Lecture).
4 Apr.	Manchester	J. A. Kuyser: "Protective Apparatus for Turbo-Generators."
5 Apr.	Birmingham	Exhibition of the cinematograph films shown in London on 12th January.
10 Apr.	Newcastle	Annual General Meeting of the North-Eastern Centre.
11 Apr.	Glasgow	F. P. Whitaker: "Rotary Converters, with special reference to Railway Electrification." Annual General Meeting of the Scottish Centre.
11 Apr.	Manchester	Informal Discussion on "Mercury Arc Rectifiers" (introduced by Mr. R. L. Morrison).
12 Apr.	Leeds	Visit of the President, Mr. J. S. Highfield.
19 Apr.	Sheffield	Visit of the President, Mr. J. S. Highfield.
24 Apr.	Liverpool	J. W. Beauchamp: "Publicity and the Electrical Development Association" (Informal Meeting).
25 Apr.	Leeds	Annual General Meeting of the North Midland Centre.
25 Apr.	Loughborough	R. J. Mitchell: "Electric Vehicles" (Lecture).
25 Apr.	Manchester	Annual General Meeting of the North-Western Centre. J. W. Beauchamp: "Publicity and the Electrical Development Association" (Lecture).
26 Apr.	Birmingham	L. Romero and J. B. Palmer: "The Interconnection of Alternating-current Power Stations."
28 Apr.	Dundee	Dr. S. P. Smith: "Single- and Three-Phase Commutator Motors with Shunt and Series Characteristics." (Lecture, to be followed by a discussion.)
28 Apr.	Manchester	Prof. W. L. Bragg: "Recent Developments in Atomic Research" (Public Lecture).
1 May	Cardiff	J. Anderson: "Electric Motor Starters."
8 May	Liverpool	Annual General Meeting of the Liverpool Sub-Centre.
9 May	Loughborough	Annual General Meeting of the East Midland Sub-Centre.

LONDON STUDENTS' SECTION.

Meetings.

(Fridays.)

[To be held at The Institution, Savoy Place, Victoria Embankment, London, W.C. 2, at 7 p.m.]

Date. 1922.	*Author and Title of Paper.*
5 May	R. P. Howgrave-Graham: "Electrically Oscillatory Discharges" (Lecture).
19 May	A. H. Reeves: "The Elimination of Atmospherics in Radio-Telegraphy." Annual General Meeting of the London Students' Section.

Visits to Works.

Date. 1922.	*Works to be Visited.*
7 Apr. (Afternoon)	Macfarlane, Lang & Co., Fulham.
29 Apr. (Morning)	Fuller Electrical Co., Walthamstow.
13 May. (Afternoon)	Victoria Telephone Exchange.
27 May. (Morning)	Electrical Apparatus Co., Vauxhall.

The above visits are open *only* to Students of the Institution. Students wishing to attend must notify Mr. H. J. Howard, 115, Queen's Road, Wimbledon, S.W. 19, at least 10 days before the visit. When the number of the party is limited the Committee reserve the right to decide, by ballot or otherwise, which Students may attend.

Council's Nominations for Election to the Council.

The following have been nominated by the Council for the vacancies which will occur in the offices of President, Vice-Presidents, Honorary Treasurer, and Ordinary Members of Council on the 30th September next:

President. (*One Vacancy.*)

F. Gill.

Vice-Presidents. (*Two Vacancies.*)

W. H. Eccles, D.Sc., F.R.S. A. A. C. Swinton, F.R.S.

Honorary Treasurer. (*One Vacancy.*)

Sir James Devonshire, K.B.E.

Ordinary Members of Council.

Members. (*Three Vacancies.*)

J. W. Beauchamp. Major K. Edgcumbe.
A. C. Cramb. C. C. Garrard, Ph.D.
W. M. Selvey.

Associate Members. (*Three Vacancies.*)

F. W. Crawter. A. B. Hart.
W. R. Rawlings.

Associates. (*One Vacancy.*)

D. N. Dunlop.

List of Members.

A new List of Members of the Institution (corrected to 1st December, 1921) is ready. Members desirous of having a copy can obtain one on application to the Secretary.

Annual Conversazione.

The Annual Conversazione will be held at the Natural History Museum, South Kensington, by permission of the Trustees of the Museum, on Thursday, 29th June, 1922.

T. A. Edison.

A letter of congratulation has been sent on behalf of the Institution to Mr. T. A. Edison, Member, on the occasion of his 75th birthday.

Aberdeen Sub-Centre.

The Committee of the Aberdeen Sub-Centre have passed a resolution to the effect that in their opinion the number of members in the district does not warrant the continuance of the Sub-Centre, and the Council have, with much regret, decided that the Sub-Centre be dissolved.

New Students' Sections.

The Council have approved the formation of Students' Sections at Leeds and Sheffield.

Associate Membership Examination Results.

October 1921. Supplementary List.
(See "Institution Notes," No. 29, Page 2, December 1921).

Passed in Whole Examination.

P. H. Mason (New Zealand).

March 1922 (for Royal Corps of Signals).

Passed in the Theory of Electrical Military Signalling.

Brown, H. N., Captain (2/32 Sikh Pioneers, I.A.).
Curry, L. H., Captain (Prince of Wales's Volunteers).
Hansard, R. L., Lieutenant (R.F.A.).
McDonald, J. C., M.C., Lieutenant (Welsh Regt.).
Miller, W. E., Lieutenant (East Surrey Regt.).
Schofield, A. J. A., Captain (20th Royal Deccan Horse, I.A.).
Tyrrell, W. U., Lieutenant (Royal Ulster Rifles).
Wheeler, C., Lieutenant (Duke of Wellington's Regt.).
Wiggins, C. S., Lieutenant (Australian Staff Corps).

Informal Meetings.

The following Informal Meetings have been held:—

29th Informal Meeting (13th February, 1922).

Chairman.—Mr. F. Pooley.

Subject of Discussion.—"The Evolution of a Staff Trade Union" (introduced by Mr. J. H. Parker).

Speakers.—Messrs. W. E. Rogers, A. F. Harmer, N. Wyld, J. R. Bedford, F. C. Knowles, E. W. Jones, F. T. Hall, J. F. Crowley, D.Sc., J. R. Bowden, W. H. M. Kelman, and F. Pooley.

30th Informal Meeting (20th February, 1922).

Chairman.—Mr. E. W. Moss.

Subject of Discussion.—"The Emergency Use of Oil Fuel during the Recent Coal Strike" (introduced by Mr. E. F. Hetherington).

Speakers.—Messrs. J. R. Bowden, W. J. Marshall, L. M. Jockel, N. Huntly, C. L. Lipman, R. J. Lappin, J. Coxon, E. A. Scarborough, A. G. Hilling, and H. L. Critchley.

31st Informal Meeting (6th March, 1922).

Chairman.—Mr. E. F. Hetherington.

Subject of Discussion.—"E.H.T. Cable-Testing" (introduced by Mr. E. Ambrose).

Speakers.—Messrs. W. E. Rogers, A. F. W. Richards, R. D. Gifford, D.Sc., P. Dunsheath, E. F. Hetherington, C. Grover, C. A. Newell, A. G. Hilling, O. L. Record, G. L. Addenbrooke, W. E. Bradshaw, A. G. Kemsley, and J. D. Spark.

32nd Informal Meeting (20th March, 1922).

Chairman.—Mr. F. Pooley.

Subject of Discussion.—"The Importance of Studying Finance in Connection with Electricity Undertakings" (introduced by Mr. A. Wright).

Speakers.—Messrs. J. S. Highfield, W. A. Chamen, E. T. Ruthven Murray, H. M. Sayers, W. E. Warrilow, R. J. Mitchell, J. D. Spark, A. G. Hilling, E. W. Moss, R. W. Hughman, R. Grierson, A. B. Eason, and F. Pooley.

Addresses Wanted.

The present addresses of the following members are required for the Institution Register.

MEMBERS.

Name.	*Last Address.*
Aulton, F. P.	Vale Lodge, Sevenoaks.
Davis, Minor M.	253, Broadway, New York, U.S.A.
Drummond, G. R.	c/o F. Clifford, Esq., 58, South Street, Wilton, Wilts.
Ellson, L. H. S.	345, St. George's Terrace, Perth, Western Australia.
Jourdan, A.	Chez M. Paul Talon, Zone du Village, A Marseilles, France.
Nelson, J. Y.	Goumea, Upper Bay View Street, North Sydney, Australia.
Niwa, S. D.	945, Higashi-Umegazectro Kitaku, Osaka, Japan.
Sanders, A. G.	12, Kersley Street, Albert Bridge Road, Battersea Park, S.W. 11.

ASSOCIATE MEMBERS.

Abbott, G. J.	132, Murray Road, Rugby.
Adams, D.	38A, Smithford Street, Coventry.
Allan, J. A.	370, Lippincourt Street, Toronto, Ont.
Campbell, J. W.	The Double - Arc Electric Welders Ltd., 26, India Street, Glasgow.
Clark, H.	1, Ladbroke Gardens, W. 11.
Dainty, W. R.	c/o Standard Bank of S. Africa, 10, Clement's Lane, E.C.
Edwards, E. A.	48, Ashfield Road, Altrincham, Cheshire.
Gibson, H.	197th Street and Amsterdam Avenue, New York City, U.S.A.
Grace, C. B.	6, Winn Road, Lee, S.E. 12.
Graham, C.	15, Chester Terrace, Preston Park, Brighton.
Gray, H.	Wyldes Hollow, North End, N.W. 3.
Harvey, J. R.	87, Leyland Road, Southport.
Henderson, H. W.	c/o C.M.E.E. Dept., Air Ministry, 6, Portman Square, W.
Houghton, J. W.	3 & 5, Toronto Street, Winnipeg, Man., Canada.
James, R. N.	36, Woodside Road, Wood Green, N. 22.
Kinnes, C. B.	c/o F. W. Hammond, Esq., Marunouchi, P.O. Box 23, Tokio, Japan.
Keane, G. E.	Municipal Tramways and Electric Lighting Board, Fremantle, Australia.
Khan, A. G.	Municipal School of Technology, Manchester.
McCloskey, A. E.	Engineer-in-Chief, G.P.O., Ceylon.

ASSOCIATE MEMBERS—*continued.*

Name.	*Last Address.*
Massie, I. W., Lt.-Col., M.C., R.E.	C.R.E., Cambrai Sub-Area, A.P.O., S. 80, France.
Mills, T.	Frodingham Iron & Steel Co., Ltd., Scunthorpe, Lincs.
Nott, Miss M.	48, Abbey Road, Ashton-on-Mersey, Cheshire.
O'Brien, C. C.	Assistant Electrical Engineer, B.B. & C.I. Railway, Ajmer, India.
Phillips, I. G. E.	The Electrical Service Co., 48, Rupert Street, Piccadilly, W.1.
Pope, P. C.	Netherwood, Ledborough Lane, Beaconsfield, Bucks.
Reinold, B. E.	8, Kidbrook Grove, Blackheath, S.E. 3.
Rhodes, E. H.	Rosemount, Tudor Hill, Sutton Coldfield, Birmingham.
Shakesshaft, F.	Harlow, Earlsden Avenue, Coventry.
Stephenson, C. H.	Brinkburne, Darley Green, Knowle, Warwick.
Swain, T.	Metropolitan-Vickers Electrical Co., Ltd., B5, Clive Buildings, Calcutta.
Townshend, E. C.	Works Manager, Carriage and Wagon Shops, O. & R. Railway, Lucknow, U.P., India.
Turner, G. P.	86, St. Albans Street, St. Albans, Christchurch, New Zealand.
Upton, M. M.	122, Sandgate Road, Folkestone.
Webster, S.	32, Nest Ridge, Rawalpindi, India.
Wilson, G. S., 2nd Lieut.	101, Field Coy. R.E., B.E.F., Italy.
Wright, F.	Electrical Installation, Staff College, Quetta, India.

GRADUATES.

Andrew, D. C.	30, Chestnut Road, Peverell, Plymouth.
Andrew, W. H.	44, Percy Road, Whitley Bay, Northumberland.
Annear, J. C., Capt., R.E.	c/o C.R.E., A.P.O., S. 10, B.E.F.
Black, E. J.	Luckington, Dalkey, Ireland.
Butterfield, E.	75, Grange Road East, Middlesbrough.
Calogreedy, H. C.	8, First Avenue, Hove, Brighton.
Carter, S.	36, Lambert Street, Beverley Road, Hull.
Conville, A.	246, Marsh Lane, Bootle, Liverpool.
Daggett, A. A.	28, Ash Road, Headingley, Leeds.
Dale, J. F.	Burma General Engineering Co., Rangoon, Burma.
Dawson, E. D., Lieut., R.A.F.	214 Squadron R.A.F., Abu Sueir, Egypt.
Dowerah, B.	91, Bath Street, Rugby.
Gillespie, R. P.	7, Town Street, Rawdon, Leeds.

GRADUATES—*continued.*

Name.	*Last Address.*
Gripper, L. A.	13, Lavender Gardens, West Jesmond, Newcastle.
Hilton, C. F.	2, The Holt, Alverstoke, Hants.
Hollick, H. C.	235, London Road, Westcliff-on-Sea.
Hollingrake, J. S.	The Forth Shipbuilding Co., Ltd., Alloa.
Jackson, S. N.	20, Oaker Avenue, West Didsbury, Manchester.
Jacobs, E.	Students' Union Society, Queen's University of Belfast, Belfast.
Kypriotis, A.	56, Samos Street, Athens, Greece.
Mason, W. J.	The Laurels, St. Fagans, Cardiff.
Miller, N. H.	Top Manor Farm, Ockbrook, Derby.
Molyneux, M. J. H.	47, Rusthall Avenue, Bedford Park, W.
Paddock, W. G.	c/o G.P.O., Victoria Street, Liverpool.
Patel, A. C.	Sholapur Mills, Sholapur, via Bombay, India.
Pritt, S. E.	4, Derby Road, Lytham Road, Fulwood, Preston.
Rodriques, J. E.	19, Goldlay Road, Chelmsford.
Russell, C. R.	College of Engineering, University of Wisconsin, Madison, Wis., U.S.A.
Taylor, J. L.	397, Great Western Road, Glasgow.
Tolley, C. E.	School of Metalliferous Mines, Camborne, Cornwall.
Westwood, H.	c/o Westwood, Post Office, Torryburn, Dunfermline.
White, H. J. F.	16, Park Square, Regent's Park, N.W. 1.

STUDENTS.

Allman, E. J.	36, Charles Avenue, Whitley Bay, Northumberland.
Anderson, E.	261, Chester Road, Stretford, Manchester
Arzonie, W. A.	34, Anderton Road, Sparkbrook, Birmingham.
Bates, L. A.	74, Park Road, Wallsend-on-Tyne.
Bell, A. C.	12, Kilmarnock Road, Shawlands, Glasgow.
Burkitt, S. T.	924, Eccleshall Road, Sheffield.
Darbyshire, C. T.	93, Albert Road, Levenshulme, Manchester.
Foster, C. B.	The Avenue, Flitwick, Ampthill.
Gibbs, W. R.	21, Castlegate, York.
Harding, A. V.	75, High Street, Ilfracombe.

STUDENTS—*continued.*

Name.	*Last Address.*
Harmer, E. W.	7, Hunton Hill, Erdington, Birmingham.
Kelly, M. J.	42, Murray Road, Rugby.
Lane, F. E.	Technical College, Loughborough.
Naravanan, M. S. I.	Assistant Engineer, P.W.D., Pyinmana, Burma.
Pacheco, O. I. de C.	15, Rosemount, Keighley.
Pollard, H. H.	92, Langside Avenue, Langside, Glasgow.
Ransom, G. S.	118, Mere Road, Erdington, Birmingham.
Read, G. W.	9, Westbourne Terrace, Lancaster.
Restrepo, P. E.	35, Linden Gardens, Notting Hill Gate, W. 2.
Roberts, M. G.	20, Haddon Street, Gorse Hill, Stretford, Manchester.
Murray-Russell, H.	2, Gratton Terrace, Cricklewood, N.W. 2.
Ryde, J. W.	27, Cathcart Road, Redcliffe Gardens, S. Kensington, S.W. 7.
Senior, R. C.	26, Fitzwilliam Street, Rotherham.
Simmonds, D. H.	16, Palmeira Avenue, Westcliff-on-Sea.
Stone, D. D.	Central London Y.M.C.A., Tottenham Court Road, W. 1.
Thompson, C. L.	The Burrs, Stanley Road, Watford, Herts.
Tinsley, H.	10, St. John's Avenue, Wakefield.
Walker, C. I.	5, Pemberley Avenue, Bedford.
Wardrop, G. G.	11, Montpelier Road, Ealing, W.

ASSOCIATES.

Challoner, W.	Blackpool.
Dixon, F. C.	Marble Quarries, Makrana, Rajputana, India.
Felce, D. H.	Monabarie Tea Estate, Mijikajan P.O., Assam, India.
Franki, R. J. N.	707, Culwalla Chambers, Castlereagh Street, Sydney, Australia.
Harris, D. G.	Irrigation Secretariat, Allahabad, U.P., India.
Nicholson, F. H.	46, Leinster Gardens, Lancaster Gate, W.
Sitwell, N. S. H., Major, R.A.	Kirkee, Bombay Presidency, India.
Stephenson, C. A.	3, Mostyn Road, Merton, Surrey.
Twemlow, F. C.	132, Bury New Road, Higher Broughton, Manchester.

THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 33. MAY 1922. INSTITUTION NOTES. [ISSUED WITH No. 309 OF THE JOURNAL.]

Council for the Year 1922–23.

At the Ordinary Meeting on the 18th May, 1922, the result of the ballot to fill the vacancies which will occur in the Council on the 30th September next was reported as follows :—

President : Mr. F. Gill.

Vice-Presidents : Dr. W. H. Eccles, F.R.S., and Mr. A. A. Campbell Swinton, F.R.S.

Hon. Treasurer : Sir James Devonshire, K.B.E.

Ordinary Members of Council : (Members) Messrs. J. W. Beauchamp, R. A. Chattock, and Major K. Edgcumbe ; (Associate Members) Messrs. F. W. Crawter, A. F. Harmer and W. R. Rawlings ; (Associate) Mr. D. N. Dunlop.

The Council for the year 1922–23 will therefore be constituted as follows :—

President.

F. Gill.

The Past-Presidents.

Vice-Presidents.

W. H. Eccles, D.Sc., F.R.S. C. C. Paterson, O.B.E.
Prof. E. W. Marchant, D.Sc. A. A. C. Swinton, F.R.S.

Honorary Treasurer.

Sir James Devonshire, K.B.E.

Ordinary Members of Council.

J. W. Beauchamp.
R. A. Chattock.
F. W. Crawter.
D. N. Dunlop.
Major K. Edgcumbe.
S. Evershed.
A. F. Harmer.
P. V. Hunter, C.B.E.
Lt.-Col. F. A. Cortez Leigh, T.D., R.E.
A. H. W. Marshall.
Sir William Noble.
Sir Andrew M. Ogilvie, K.B.E., C.B.
A. Page.
W. R. Rawlings.
T. Roles.
A. Russell, D.Sc.
A. W. Tait, C.B.E.
C. Vernier,

and

The Chairman and immediate Past-Chairman of each Local Centre.

Wireless Section Committee, 1922–23.

The following members have been nominated by the Wireless Section Committee to serve on the Committee for 1922–23 :—

Chairman : Professor G. W. O. Howe, D.Sc.

Ordinary Members of the Committee : Dr. S. Brydon, Mr. J. St. Vincent Pletts, Captain H. R. Sankey, C.B., C.B.E., R.E., and Mr. R. L. Smith-Rose, B.Sc.

And the following will continue to serve :—

Mr. B. Binyon, O.B.E., Mr. R. C. Clinker, Dr. W. H. Eccles, F.R.S., Professor C. L. Fortescue, Mr. G. H. Nash, C.B.E., Mr. C. C. Paterson, O.B.E., Captain H. J. Round, M.C., and Mr. L. B. Turner, M.A.

At the meeting of the Wireless Section on the 7th June, 1922, the Chairman announced that no further nominations having been received, the above, together with representatives of the Admiralty, the War Office, the Air Ministry and the Post Office, will constitute the Committee for the year 1922–23.

Associate Membership Examination Results.

The following is a list of the successful candidates at the examination held in Great Britain in April last :—

Whole Examination.

Abbott, A. J.
Atkinson, C. E.
Bullock, P. C.
Campbell, F. W.
Cassall, C. V.
Catling, A. B.
Coates, A. W.
Dawe, R. E.
Fisher, A. W.
Gordon-Campbell, W. F.
Hall, D. K.
Hopkin, D. W.
Inman, V. H. T.
Johnson, E. M.
Jones, J. C.
Josephs, A.
King, S.
Knight, R. P.
Lambert, G. W.
Lanes, F.
Lingard, H.
Monk, S. G.
Newhouse, K. H. A.
Paddle, L. H.
Park, H. E.
Polydoroff, W. J.
Ramsdale, W. S.
Richards, A. S.
Rook, E. B.
Rowbotham, J. L.
Shepherd, J. E.
Southgate, A.
Sowerbutts, C. A.
Sparks, H. C.
Thirtle, A. C.
Tyrrell, D. W.

Part II Only.

Atkins, R. E.
Bedford, J. A.
Cameron-Kirby, C.
Desborough, J. W. H.
Gorton, E. J.
Groves, L. C.
Hampson, W. P.
Hinds, G. A. R.
Hovanesian, W.
Kay, H. H.
Minton, W. J.
Nichols, F. R
Pennell, E. R.
Pitt, F. E.
Sprackling, J. H.
Webb, A. J.

Part I Only.

Fuke, F. C.
Telfer, F. P. G

[The results relating to candidates who sat for the examination abroad will be published later.]

CORPS OF ROYAL ENGINEERS.

Whole Examination.

Angwin, J. B. P., Lieutenant.
Baines, J. S., Captain.
Bennetts, A., Lieutenant.
Blagden, W. M., Lieutenant.
Fryer, W. G., Lieutenant.
Gadd, A. G., Lieutenant.
Kenyon, L. F. R., Lieutenant.
Lloyd, B. H. S., 2nd Lieut.
Macdonald, A. J., Lieutenant.
St. George, H. E. G., Lieutenant.
Simpson, J. R., 2nd Lieut.
Stewart, G. M., Lieutenant.
Stuart, J., Lieutenant.
Walker, R. C., Lieutenant.
Wyatt, A. G., 2nd Lieut.

Part I Only.

Anketell, W. H. R., 2nd Lieutenant.

ROYAL CORPS OF SIGNALS.

Whole Examination.

Ozanne, G. D., Captain (A/Major) Indian Army.
Wade, D. A. L., Lieutenant (A/Capt.).

Electrical Research.

The Secretary of the Institution has received the following from the British Electrical and Allied Industries Research Association :

QUARTERLY REVIEW OF PROGRESS (APRIL, 1922).

SECTION A : FIBROUS INSULATING MATERIALS.

Fabrics, treated.—Methods of testing the properties of materials of this class have been drafted in detail and good progress made in checking them experimentally.

Papers, untreated.—A technical publication (Ref. A/S1) has been issued giving instructions for the study of electrical insulating papers (untreated) for purposes other than the manufacture of cables, and will appear shortly in the technical Press. A full report on the researches leading up to this publication has been completed and will be published immediately.

Hard fibres, boards and tubes.—A technical report has been prepared dealing with the study of pressboards, which group includes press-spahn, leatherboard, fullerboard and the like. The report describes all the researches made in the development of the methods of testing recommended and gives characteristic results. This will be published immediately to members and in part through the technical Press. Good progress has been made in the study of vulcanized fibres, and a similar report is approaching completion. Arrangements are being made for a comprehensive series of comparative tests of available products to be carried out for the benefit of members in accordance with the methods now developed. Samples are being obtained for the purpose.

Varnishes.—A Committee has been formed to deal in the first place with problems of classification and terminology, and to advise on the materials for use in researches on treated paper and fabric.

Electrical tests.—A publication dealing comprehensively with the electrical testing of fibrous insulating materials has been completed and will be issued to interested members. Steps are being taken by the Association to extend this work to cover the testing of insulating materials of all kinds, with a view to ultimate standardization of method.

SECTION B : COMPOSITE INSULATING MATERIALS.

A publication (Ref. B/S1) has been issued dealing with the study of hard composite insulating materials ; whether mouldings or in the form of sheets, rods and tubes. This will appear shortly in the technical Press. A comprehensive report on the experimental researches leading up to this document has been prepared for publication. Manufacturers who co-operated have had the benefit of the results obtained, and marked improvements in products have already been made.

Attention is being given to the fire- and heat-resisting group. Methods of testing have been developed experimentally and will now be applied to materials on the market. Consideration is being given also to moulding properties, action of solvents and of hot oil.

SECTION C : PORCELAIN.

Manufacturers have supplied a number of samples of porcelain manufactured under commercial production conditions and representing the more important grades used in the electrical industry. The electrical properties are being investigated under a variety of conditions including a wide range of temperature. A relationship has been obtained between the character of the glaze and ability to resist the accumulation of impurities from the atmosphere.

SECTION D : MICA AND MICANITE.

Reports have been sent to members and to the technical Press dealing with the classification, identification and properties of mica, its use in commutating machinery and condenser manufacture.

Good progress is being made in the further study of the properties of the different kinds of mica, mechanical tests are being developed, and systematic electrical tests are producing new data.

Inquiry has shown that there is need of investigation into the classification, manufacture and use of micanite for all purposes, and steps have been taken to bring together the interested parties.

Section E : Insulating Oils.

Specification for insulating oils.—The draft Standard Specification has been returned to the B.E.S.A. with recommendations dealing with the features referred back to the Association.

Researches on electric strength and resistivity.—A programme of research has been prepared in co-operation with Professor J. A. Fleming to be carried out in the near future at London University. Meanwhile all available data are being studied, and further tests are being carried out with different arrangements of spark gap and with centrifugal separators.

Latent heat and thermal conductivity.—Tests have been made on representative samples of insulating oils and data obtained which will be useful in the investigations on arcing phenomena and on thermal transference.

Other researches.—Further progress has been made on sludge testing, effect of catalysers, and on effects of arcing under oil.

Section F : Conductors.

Heating of buried cables.—The investigators are now preparing a report furnishing the data for disposing of most of the outstanding problems other than those in which dielectric losses are important.

Tests on wood poles for overhead lines.—The results obtained on standard poles are now being reduced to a form suitable for publication. The results suggest directions in which material improvements might be made, and the Committee is awaiting tests now being carried out on small scale models by Mr. W. B. Woodhouse.

Overhead line conductors.—The tests on copper cables carried out on long lengths under working conditions have been completed and a report is in preparation. The tests on aluminium and steel cables are nearly finished.

Section G : Electric Control Apparatus.

Tests on oil circuit breakers.—Exhaustive tests have been made on the characteristics of the 6 000-kW alternator which will be employed in this investigation. The measuring and recording apparatus and artificial loads are nearly ready, good progress having been made in the development of methods of recording pressure waves, and in controlling the conditions of test.

Mining switchgear.—Based on the data obtained from preliminary models, apparatus is now being devised for completing the investigation of pressures developed in closed chambers resulting from electric short-circuits. Good progress has been made in the development of apparatus for investigating methods of relieving pressure.

Fusible cut-outs.—Methods of testing British Standard ordinary-duty fusible cut-outs have been proved and a number of designs are under investigation, including those mounted in iron boxes.

Air-break circuit breakers.—Tests are being put in hand for the study of d.c. circuit breakers, and the characteristics of d.c. circuits as met with in practice, with the assistance of the Engineering Departments of the London County Council and the London & North-Western Railway.

Joints and contacts.—A valuable report has been received from the National Physical Laboratory on the conductivity of joints between rectangular bars in copper and aluminium which will be published shortly by the Laboratory. Further tests on joints in existing busbars and connections in large power stations have been arranged for.

Section H : Corrosion of Metals.

The Association is awaiting a report from the Institute of Metals.

Section J : Turbines.

The research programme on turbine blading is being revised in the light of recent researches on stainless steel. Good progress is being made in the research on nozzles at Manchester University in which the Association is participating. Professor Callendar will carry out further research on turbines, and attention is being given also to the properties of steam at high temperatures and pressures.

Section K : Synthetic Resins.

A report has been prepared on the possibilities of developing in this country the production of raw materials from which the synthetic resins can be produced, and methods of ensuring supplies.

A technical publication has been prepared giving directions for the study of synthetic resin varnish-paper and varnish-fabric boards and tubes. A number of samples are being obtained for comparative tests. A programme of tests on moulded products is well in hand and samples are being got.

A report showing the requirements of Government Departments is being distributed to members concerned.

Section L : Dielectrics in General.

The research on dielectric losses and allied phenomena is being actively pursued, and interesting data are coming to hand. New methods of test are being developed and new results obtained. Apparatus for the investigation of thermal conductivity has been completed, and tests are in hand. The possibilities of the cathode ray tube as an instrument for dielectric loss measurements at high frequencies are being investigated, and a programme of research on dielectric losses at high voltages with an electrostatic wattmeter is in preparation.

Miscellaneous Researches and Inquiries.

Tests are being made to verify data on the permissible cyclic variation of supply voltage in relation to flicker of incandescent lamps. Further conferences with representatives of Government Departments interested in accumulators and primary batteries have been held. Researches on wave-form of generators and numerous other matters are under consideration.

Accessions to the Lending Library.

BANGAY, R. D. The elementary principles of wireless telegraphy. [2nd ed.].
2 pts. [in 1 vol.]. sm. 8vo. *London*, 1918–22

——— The oscillation valve. The elementary principles of its application to wireless telegraphy.
sm. 8vo. 223 pp. *London*, 1920

BISACRE, F. F. P. Applied calculus. An introductory textbook. sm. 8vo. 460 pp. *London*, 1921

BOND, W. G. The rating of electric lighting, electric tramway and similar undertakings.
8vo. 29 pp. *London*, [1903]

BUCHER, E. E. Technical description of the Alexanderson system for radio telegraph and radio telephone transmission.
4to. 55 pp. [*New York*, 1920]

BURNS, DANIEL. Electrical practice in collieries. 5th ed.
sm. 8vo. 417 pp. *London*, 1920

COURSEY, P. R. The radio experimenter's handbook.
8vo. 119 pp. *London*, 1922

CROWTHER, J. A. Ions, electrons, and ionizing radiations. 3rd ed. 8vo. 304 pp. *London*, 1922

DUNCAN, J., and STARLING, S. G. A textbook of physics. 8vo. 1116 pp. *London*, 1920

GIBSON, A. H., *editor*. Hydro-electric engineering. vol. 1, Civil and mechanical. Contributors: H. D. Cook and the Editor.
la. 8vo. 242 pp. *London*, 1921

HALL, B. J. Blue printing and modern plan copying.
8vo. 139 pp. *London*, 1921

HAUSMANN, E. Telegraph engineering. A manual for practising telegraph engineers and engineering students. 8vo. 418 pp. *London*, 1915

HAWKINS, C. C. The dynamo: its theory, design, and manufacture. 6th ed. vol. 1.
8vo. 638 pp. *London*, 1922
The earlier editions of this work are by C. C. Hawkins and F. Wallis.

HAYES, S. Q. Switching equipment for power control.
8vo. 470 pp. *New York*, 1921

LAMB, C. G. Alternating currents.
2 pts. 8vo. *Cambridge*, 1921

LAWRENCE, R. R. Principles of alternating current machinery. 2nd ed.
8vo. 631 pp. *New York*, 1921

PIDDUCK, F. B. A treatise on electricity.
8vo. 660 pp. *Cambridge*, 1916

RICHARDSON, O. W., *F.R.S.* The emission of electricity from hot bodies. 2nd ed.
8vo. 328 pp. *London*, 1921

STARLING, S. G. Science in the service of man: Electricity. 8vo. 253 pp. *London*, 1922

STEINMETZ, C. P. Theory and calculation of electric circuits. 8vo. 377 pp. *New York*, 1917

THOMSON, *Sir* J. J., *O.M., F.R.S.* Rays of positive electricity and their application to chemical analyses. 2nd ed. 8vo. 247 pp. *London*, 1921

TIMBIE, W. H. Essentials of electricity. A textbook for wiremen and the electrical trades. Direct currents. sm. 8vo. 284 pp. *New York*, [1912

TODD, V. H. Protective relays. Their theory, design, and practical operation.
8vo. 286 pp. *New York*, 1922

WHEELER, S. G. Entropy as a tangible conception. An elementary treatise on the physical aspects of heat, and thermal inertia for designers, students, and engineers and particularly for users of steam charts. 8vo. 76 pp. *London*, 1921

THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 34. AUGUST 1922. INSTITUTION NOTES. [ISSUED WITH No. 312 OF THE JOURNAL.]

North-Western Centre.

Mr. W. A. Coates, who had been appointed to succeed Mr. A. G. Ellis as Hon. Secretary of the above Centre, having left England to take up a position in Tokio, Mr. A. B. Mallinson has been elected to the office by the Committee of the North-Western Centre.

"Science Abstracts."

On the recommendation of the Committee of Management of *Science Abstracts*, the Council have appointed Mr. W. R. Cooper, M.A., B.Sc., M.I.E.E., to be Editor of the publication in the place of the late Mr. L. H. Walter.

Mr. Cooper was Acting Editor of *Science Abstracts* in the first year of its existence, 1898, and Editor from 1899 to 1901.

Associate Membership Examination Results.

APRIL 1922, SUPPLEMENTARY LIST.
(SEE "INSTITUTION NOTES," No. 33, PAGE 21, MAY 1922.)

Passed in Part II.

H. W. Cockerill (New Zealand).

Students' Premiums.

The Council have awarded the following Premiums, each of the value of £10, for Papers read before the Students' Sections during the Session 1921-22.

Author	*Title of Paper and where read*
J. A. COOPER ..	"Long Distance Telephony" (Birmingham).
C. DAWSON ..	"Testing of Materials used in the Manufacture of Electrical Machinery" (Birmingham).
F. C. LAWRENCE .	"The Engineer and Manufacturing Cost" (Manchester).
H. S. PETCH ..	"Automatic and Semi-automatic Railway Signalling" (London).
J. C. STEWART ..	"Electricity in Mines" (Glasgow).
A. TUSTIN ..	"Hydro-electric Power Supply" (Manchester).

Scholarships.

The following Scholarships have been awarded by the Council:—

Salomons Scholarship (value £50) to:—Mr. A. H. Maggs (Bristol University).

David Hughes Scholarship (value £40) to:—Mr. W. H. N. Hellier (University College, Cardiff).

Paul Scholarship (value £50) to:—Mr. C. A. Wilck (Finsbury Technical College, London).

Engineering Joint Council.

A Committee consisting of representatives of the following institutions:—

The Institution of Civil Engineers,
The Institution of Mechanical Engineers,
The Institution of Naval Architects,
The Institution of Electrical Engineers,

considered during the past session the formation of an Engineering Joint Council and recommended the following constitution, which has been approved by the four Institutions named:

ENGINEERING JOINT COUNCIL.

1. A Council to be entitled "The Engineering Joint Council" shall be formed. It shall consist of two members of the Councils of each of the following Institutions in the first instance, appointed from time time by their Councils severally:—

The Institution of Civil Engineers,
The Institution of Mechanical Engineers,
The Institution of Naval Architects,
The Institution of Electrical Engineers.

2. The members of the Joint Council shall be appointed annually, and shall be eligible to serve for not more than four years consecutively. One of the first two appointed by each Institution shall serve for not more than two years, but shall be eligible for re-appointment for a further period of not more than four years consecutively.

3. The Chairman shall be elected annually by the Joint Council, and the Secretary of the Institution represented by the Chairman for the year shall act as Secretary of the Joint Council. The Chairman shall be chosen from the several Institutions in rotation.

4. The Joint Council shall consider matters referred to it by the Council of any one of the constituent Institutions. It shall not initiate proposals affecting the Institutions.

The first Council will be constituted as follows:

Name	*Nominated by*
Sir M. Fitzmaurice Mr. W. B. Worthington	The Institution of Civil Engineers.
Capt. H. R. Sankey Mr. W. H. Patchell	The Institution of Mechanical Engineers.
Two representatives to be nominated	The Institution of Naval Architects.
Mr. J. S. Highfield Mr. R. T. Smith	The Institution of Electrical Engineers.

List of Members.

Copies of the latest List of Members, corrected up to 1st December, 1921, are still available, and can be obtained on application to the Secretary.

Summer Meeting, 1922.

The Summer Meeting of the Institution in Scotland, originally arranged to take place in 1921 but postponed on account of the Coal Strike of that year, took place from the 30th May to the 2nd June, 1922.

The party was under the leadership of the President (Mr. J. S. Highfield) and numbered about 360 (including 95 ladies) during the Glasgow portion of the meeting, of whom 260 took part in the excursion to the Western Highlands which occupied the last two days.

The Meeting commenced on Tuesday, 30th May, with an official reception of the visitors at the Royal Technical College by the Lord Provost (Mr. Thomas Paxton) and some of the City Magistrates, after which Mr. R. B. Mitchell read a short paper describing the Dalmarnock Power Station.* The party were then conveyed in special tramcars to inspect the power station, over which they were conducted by Mr. Mitchell and his assistants. At the conclusion of this visit the party proceeded to the Municipal Buildings where they were entertained at lunch by the Glasgow Corporation Electricity and Tramways Committees, the chair being taken by the Lord Provost. A number of influential citizens were also present.

In the afternoon while a large section of the party were being conducted over the Clydes Mill Power Station by Mr. E. T. Goslin and entertained to tea by the Clyde Valley Electrical Power Co., another section almost equally large made a circular excursion by motor coaches *via* Bearsden, Stockiemuir, Blanefield, etc., to the Corporation Reservoirs at Milngavie, where tea was provided on the lawn. The return to the city was made by a shorter route through Hillfoot and Maryhill. A very strenuous day ended with further hospitality from the Corporation at the Municipal Buildings where, after a Reception by the Lord Provost and the Corporation, an excellent Concert was given in the Council Chamber and there was dancing in the adjoining Hall.

The proceedings on Wednesday, 31st May, began with a lecture by Professor Magnus Maclean, delivered in Lord Kelvin's lecture theatre at the University, on "The Hydro-Electric Resources of the Scottish Highlands," an account of which will be found in the *Journal* (see page 902). Special tramcars were again provided by the Corporation to convey the party to and from the University.

The afternoon was taken up with an excursion, by invitation of Messrs. Babcock & Wilcox, Ltd., to their works at Renfrew, where the various operations in the manufacture of boilers, automatic stokers, coal and ash handling plants, and cranes and transporters, were seen in progress. The T.S.S. "Queen Alexandra" was specially chartered by the hosts for this visit, and the party were afterwards taken for a most pleasant cruise through the Kyles of Bute. Tea and dinner were served on board. With the return to Glasgow the first portion of the meeting ended.

The excursion to the West Highlands was principally with the object of visiting the works of the British Aluminium Company at Kinlochleven, but the journey through the varying Highland scenery was one of the most enjoyable experiences of the Meeting. The party left Glasgow for Fort William by special train on Thursday morning, 1st June. A halt was made at Tulloch for a picnic lunch, and some of the members took the opportunity of inspecting the source of supply of the new Lochaber power scheme referred to by Professor Magnus Maclean in his lecture the previous day. Fort William was reached in time for tea. An early start was made on Friday morning for Kinlochleven by steamer *via* Loch Linnhe and Loch Leven. At Kinlochleven, which was reached at about 11 a.m., the party were welcomed by Mr. W. Murray Morrison and the staff of the British Aluminium Company. After the plant, works and the various processes had been inspected, the visitors were entertained at lunch by the Company.

Oban was reached by steamer in the evening, and here the meeting ended, the party breaking up on the Saturday morning (June 3rd).

The thanks of the visitors are especially due to the Lord Provost and Corporation of Glasgow, Messrs. Babcock & Wilcox, Ltd., and the British Aluminium Company, Ltd., for their hospitality, and to Mr. E. T. Goslin (*Chairman*), Mr. Joseph Taylor (*Honorary Secretary*), and the Committee of the Scottish Centre, whose work in organizing the Meeting was rewarded by its undoubted success. Thanks are also due to the Caledonian Railway Company who, through Mr. R. Killin (*Superintendent of the Line*) and Mr. A. S. Hampton (*Electrical Engineer*), granted valuable facilities which added considerably to the comfort of the party, and to the L. & N.W. Railway Company who, through the good offices of Lieut.-Colonel F. A. Cortez Leigh, provided a special dining coach from London to Glasgow on the 29th May.

* *Transactions of the Institution of Engineers and Shipbuilders in Scotland*, 1921, vol. 64, p. 398.

Students' Summer Visit, 1922.

REPORT OF HON. SECRETARY.

This year the London Students joined forces with the Graduates Association of the Institution of Mechanical Engineers for the purpose of a joint visit to the Cardiff district. The visit commenced on Monday, July 24th, with an informal dinner at Barry's Hotel, Cardiff, the headquarters of the party during the visit. The visitors were welcomed on this occasion by Mr. David E. Roberts, Professor E. Bacon and Eng.-Commander W. H. Reynolds, the Chairman and Joint Hon. Secretaries respectively of the Local Branch of the Institution of Mechanical Engineers. It was unfortunate that, owing to a previous engagement, the corresponding I.E.E. officers were unable to attend.

On Tuesday the party visited the Melingriffith tin-plate works, where they were received and conducted round the factory by Mr. W. R. Davies, the works manager. The whole of the process was inspected from the roll-

ing of the sheets, through the pickling and annealing shops, to the final tinning. Here the Thomas & Davies tinning machine was seen at work, the salient feature being the novel manner in which the plates are fed into the machine. This is effected by a rocking arm fitted with a sucker which comes down on to a pile of plates and removes the top plate by suction. Luncheon was taken at the works. The party proceeded in the afternoon by the firm's private railway to the base of the Garth Mountain and returned from St. Fagans by train to Cardiff.

On Wednesday the party visited Swansea, and were met by members of the Association of Engineering Students of the University College of Swansea. Messrs. Vivian's Hafod copper works and Messrs. Baldwin's Landere steel works were visited. The party lunched at the Exchange Restaurant, where they were joined by Mr. J. W. Burr, Borough Electrical Engineer. The afternoon was taken up by a cliff walk from the Mumbles to Langland Bay, and the party returned to Cardiff by train.

On Thursday the party were conducted over the underground workings of the Britannia pit of the Powell Duffryn Steam Coal Co. An interesting feature of the colliery is the winding gear, which is operated on the Ilgner principle. In the evening there was a boat trip to Weston.

On Friday a visit was made to the Barry Docks and Railway works, Mr. Pennington, the Docks Superintendent, personally conducting the party. In the afternoon the Aberthaw and Bristol Channel Cement Works were visited, the party being entertained to tea by the firm. In the evening they were the guests of the Local Centres of the two Institutions at the Electric Café.

On Saturday the tour was brought to a close by a visit to the Municipal Buildings, led by Mr. C. T. Allan, the Joint Hon. Secretary of the I.E.E. Western Centre.

The London Students' Committee wish to express their thanks to all those friends in South Wales who did everything possible to make the visit a success.

Royal Naval Volunteer Reserve.

The Secretary has been asked to bring the following to the notice of members :—

Recruits are wanted for the Royal Naval Volunteer Reserve Force at the six Divisional areas round the coast of Great Britain. Several of the Naval Branches (such as torpedo, electrical artificers, mining, wireless telegraphy, etc.) in which the R.N.V.R. ratings are trained require a knowledge of electricity, and the Royal Naval Volunteer Reserve Committee request employers in the Command areas to draw the attention of their employees to this Force and encourage suitable men to join it. A large number of members of the Institution, and of the electrical engineering profession in general, served with the R.N.V.R. during the war, thereby assisting to build up the traditions of that Force ; and the Committee therefore hope that this appeal will meet with ready support.

Full particulars as to entry and terms of service can be obtained from the Commanding Officers in the following districts :—

London Division R.N.V.R. : H.M.S. "President," Victoria Embankment, E.C. 4.

Bristol Division, R.N.V.R. : 37, Jamaica Street, Bristol.

Sussex Division, R.N.V.R. : 5, Victoria Terrace, Hove ; R.N.V.R. Battery, Eastbourne ; R.N.V.R. Battery, Hastings ; and R.N.V.R. Battery, Newhaven.

Mersey Division, R.N.V.R. : H.M.S. "Eaglet," Salthouse Dock, Liverpool ; Manchester Sub-Division (Temporary Headquarters), Salford Workhouse, Salford.

Tyneside Division, R.N.V.R. : H.M.S. "Helicon," Newcastle-on-Tyne ; and H.M.S. "Satellite," North Shields.

Clyde Division, R.N.V.R. : Whitefield Road, Govan, Glasgow ; H.M.S. "Unicorn," Dundee ; and H.M.S. "M.23," Leith.

The British Electrical and Allied Industries Research Association.

QUARTERLY REVIEW OF PROGRESS (JULY 1922).

SECTION A : FIBROUS INSULATING MATERIALS.

Fabrics.—The leading manufacturers, who are co-operating in this research, are now preparing samples of varnished fabric under controlled working conditions for the investigation of the technical problems involved in the improvement of this important group of materials.

Papers.—The classification of materials, uses, properties and methods of testing having been completed and published, the Association is now applying these methods to the improvement of the product, and to this end is obtaining the co-operation of leading paper manufacturers who are devoting special attention to the requirements of the electrical industry.

Attention is being given also to the effects of raising the working temperatures.

Hard fibres, boards and tubes.—Methods have now been developed experimentally for the study of vulcanized fibres with a view to their improvement, and based on data and experience gained during the investigation proposals have been drafted for a purchasing specification.

Varnishes.—A preliminary classification of varnishes has been prepared and samples are being obtained from the leading manufacturers for the development of methods of testing, and for use in the investigations on varnished fabric and paper. Special attention is being given to causes of serious variations of quality in synthetic resin products and shellac, with a view to their elimination.

SECTION B : COMPOSITE INSULATING MATERIALS.

A comprehensive report has now been prepared for the information of members on the completed research work on hard composite dielectrics.

Attention has now been directed to the heat-resisting group of composite and fibrous materials. Methods of testing have been developed and samples are being obtained from manufacturers.

Section C: Porcelain.

A programme of research on mechanical properties is in preparation. Some preliminary reports have been received of the comprehensive research being carried out at Manchester University.

Section D: Mica and Micanite.

Properties of mica.—Methods of testing hardness, elasticity, and flexibility have been developed, and preliminary results obtained on two representative micas. It is intended to make a survey of these properties in micas of the different kinds from various sources.

Micanite.—A classification of micanites has been made, in relation to properties, use, and method of manufacture, and the limitations of each class are being studied. Methods of testing are being developed with a view to future standardization.

Section E: Insulating Oils.

Electric strength.—Further research is in hand to determine the relative merits of the horizontal and vertical arrangements of sphere gaps.

Full consideration has been given to the proposals of the American Society for Testing Materials, and a report has been prepared showing the bearing of the work of the Association on these proposals and the reasons which have led the Association to adopt the sphere gap in preference to all others.

Centrifugal separation.—Reports of work done in the U.S.A. have been obtained and studied, and experimental work carried out with De Laval separators. This work is still incomplete, but shows promise of useful developments of commercial methods of improving the electric strength and maintaining the condition of insulating oils.

Research on sludge.—Opportunity has been taken of the presence of Mr. Evert Norlin of the Government Testing Institute of Sweden in this country to discuss the methods employed on the Continent and in America for the determination of sludge and tar values and the evidence on which they are based. A programme of further qualitative research is now in preparation.

Section F: Conductors.

Heating of buried cables.—Tables are now being prepared showing the safe loading of British Standard Cables for electric power and lighting up to 11 000 volts, taking account of ground temperature and moisture content of the soil. A satisfactory method has been developed of applying to three-core cables the results of tests on single-core cables. A report is in preparation to accompany the tables, and further reports on the effect of grouping and intermittent loading.

The preparation of tables for the higher voltages awaits the results of investigations on dielectric losses.

Wood poles for overhead lines.—Based on the result of tests made on **A** and **H** poles under working conditions the Association is engaged in studying alterations of construction which promise to give considerable improvement.

Overhead line conductors.—Experimental work has now been completed for determining the modulus of elasticity and other physical properties of wires and cables of copper, aluminium, steel-cored aluminium and galvanized steel of commercial quality as found under working condition.

Section G: Electric Control Apparatus.

Phenomena of switching and arcing.—The completion of experimental apparatus has been seriously delayed by the industrial dispute. Further advance has been made in apparatus for pressure-recording, and a high-speed camera has been devised which can be operated with a continuous feed without the usual step by step action, working at an aperture of $f\,2{\cdot}6$.

Mining apparatus.—Further experimental work has been done on the relief of pressure of gaseous explosions through flanged joints, and some unexpected results have been obtained. A programme has been prepared for extending this investigation to cover other methods of pressure relief.

Section J: Turbine Researches.

A further report has been received of the research on nozzles. Reports have been prepared on work done in America, on the Continent, and in this country bearing on the research work of the Association on turbines.

Section L: Dielectrics in General.

Dielectric losses.—The apparatus developed by the N.P.L. for the measurement of small losses eliminating leakage current has given new results on mica, and the study of micas is approaching completion. Some preliminary data has been obtained also on varnished cloths at low voltages.

Progress has been made at the Laboratory in the development of a wattmeter for researches at high voltages, and satisfactory results have been obtained at about 10 000 volts.

Good progress has been made also by Professor MacGregor-Morris in the development of the Braun tube as an instrument for high-frequency dielectric-loss measurement.

Thermal resistivity.—Resistivity measurements on materials employed in the insulation of electrical machinery have been made in the Laboratory, and the work is now being extended by co-operation with leading manufacturers to cover constructions employed in the workshop.

Inflammability and effects of heat.—A new Committee has been formed and is considering classification of heat-resisting properties of materials, appropriate nomenclature and methods of testing, with a view to co-ordinating the work of the various interested Sections of the Association and of other bodies.

Electric strength.—A new Committee is being formed to co-ordinate methods of testing electric strength of insulating material. A programme of research has been prepared for ascertaining the limitations of tests made on sheet materials with disc electrodes, with a view to establishing the best conditions of test for each class of material and the errors to be expected under given conditions.

SUGGESTION FOR BINDING VOLUME 60.

When "Institution Notes" are bound with the *Journal* they should be inserted immediately after page 956 and be followed by this Index.

INDEX TO VOL. 60.

1922.

EXPLANATION OF ABBREVIATIONS.

(P) indicates a reference to the general title or subject of a paper or address.
(p) indicates a reference to a subject dealt with in a paper or address of which the title is not quoted.
(D) indicates a reference to a discussion upon a paper or address of which the general title or subject is quoted.
(d) indicates a reference to a subject dealt with in a discussion on a paper or address of which the general title is not quoted.

A.

Aberdeen Sub-Centre, discontinuance of. 529.
Abernethy, J. W. A. Alternating-current commutator motors. (D), 323.
Abstracts, Science, Council's report on. 531.
Accounts, Annual, for 1921. 538.
——, Annual, for 1921, Council's report on. 534.
——, Benevolent Fund, for 1921. 544.
Adams, H. Telephone line work in U.S.A. (D), 134.
Adapters, common faults of. G. H. Nisbett, (p), 47.
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